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LEVEL III (12)

RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- 78-2922-2

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ULTRA LOW LOSS OPTICAL FIBER CABLE ASSEMBLIES

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ULTRA LOW LOSS OPTICAL FIBER

CABLE ASSEMBLIES

B003

Semiannual Report

Contract DAAB07-78-C-2922

December 1, 1978 through July 31, 1979

Prepared for:

U.S. Army Electronics Command
Fort Monmouth, New Jersey

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Progress toward development of ruggedized ultra low loss (<8.0 dB/km) optical fiber cable assemblies consisting of six optical fibers is reported. Effort involves investigations of fiber, cabling, and connector development on an individual as well as combined basis for meeting requirements of tactical TDM communication systems.

During this reporting period, extensive testing and evaluation of three six-fiber cables was performed in accordance with technical guidelines.

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20. ABSTRACT (continued)

Pertinent test results are summarized herein. (Complete test data is reported elsewhere.) Program areas requiring additional investigation are described. Development status of two types of connectors is discussed and preliminary test data presented. Difficulties incurred with fiber-connector interface are identified.

PREFACE

This semiannual report describes work performed for the Center for Communications Systems, Multichannel Transmission Division, CORADCOM by ITT Electro-Optical Products Division under contract DAAB07-78-C-2922, awarded from Fort Monmouth, New Jersey. The effort is directed toward fulfilling objectives of "Technical Guidelines for Development of Ultra Low Loss Optical Fiber Cable Assemblies," dated December 1976, and in general support of the U.S. Army's fiber optic development program.

The ITT Cannon Electric Division is a subcontractor to this effort under the guidance of ITT EOPD for the required connector development.

The U.S. Army project engineer for this effort is Mr. J. W. Strozyk of the Fiber Optics Team (DRDCO-COM-RM-1).

The period of performance covered under this report was December 1978 through July 1979. The initial draft was submitted for approval on October 9, 1979.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (continued)

1.0 INTRODUCTION

The objective of the Ultra Low Loss Optical Fiber Cable Assemblies Contract (DAAB07-78-C-2922) is to develop optical fiber cable assemblies for the Army tactical field data transmission at 20 Mb/s over 8 km without repeaters.

The contract effort includes the development of rugged cable, hermaphroditic cable connectors, and bulkhead connectors which are simultaneously optimized for Army tactical field applications.

The cable development was centered on three cable designs which were submitted to CORADCOM in the cable design plan. The connector effort was divided into two approaches - jewel ferrule connector and adjustable three-sphere connector. One of these approaches would be selected during a critical design review, scheduled for July 1979. Unexpected fiber variations forced a change from a critical design review to a program review which was scheduled for August 1979. The main issues to be addressed were the low temperature fiber attenuation increases, fiber bend sensitivity, fiber diameter control, and brittleness that affect characterization of the connector designs. All of these issues are being analyzed for action in the next reporting period.

1.1 Work Planned for This Reporting Period

The following work was conducted during this reporting period:

a. Complete fabrication of preliminary design model (PDM) cable

b. Submit preliminary design model (PDM) cable samples

c. Fabricate fibers for exploratory development model (EDM) cables

d. Submit test plan

e. Fabricate exploratory development model of the three-sphere connector

2.0 PRELIMINARY DESIGN MODELS (PDMs)

This section covers the description, construction, and evaluation of the PDM cable samples.

2.1 Optical Fibers

The light transmitting elements of the cable are the graded-index optical fibers (Figure 2-1) consisting of a glass core (germanium, phosphorus, and boron dopants) and a glass cladding (germanium, phosphorus, and boron dopants). To preserve the mechanical strength of the glass fibers, they are coated with plastic buffers, the buffer being a solid plastic coating surrounding the optical fiber.

The graded-index optical fibers are to meet the following specifications at 0.82-μm wavelength after proof loading at 100,000 psi:

a.	Fiber core	56 μm ±5 μm
b.	Fiber outside diameter (od)	125 μm ±6 μm
c.	Attenuation	$\leq$5.0 dB/km
d.	Dispersion	$\leq$2.0 ns/km
e.	Numerical aperture (NA) (90% power)	$\geq$0.14

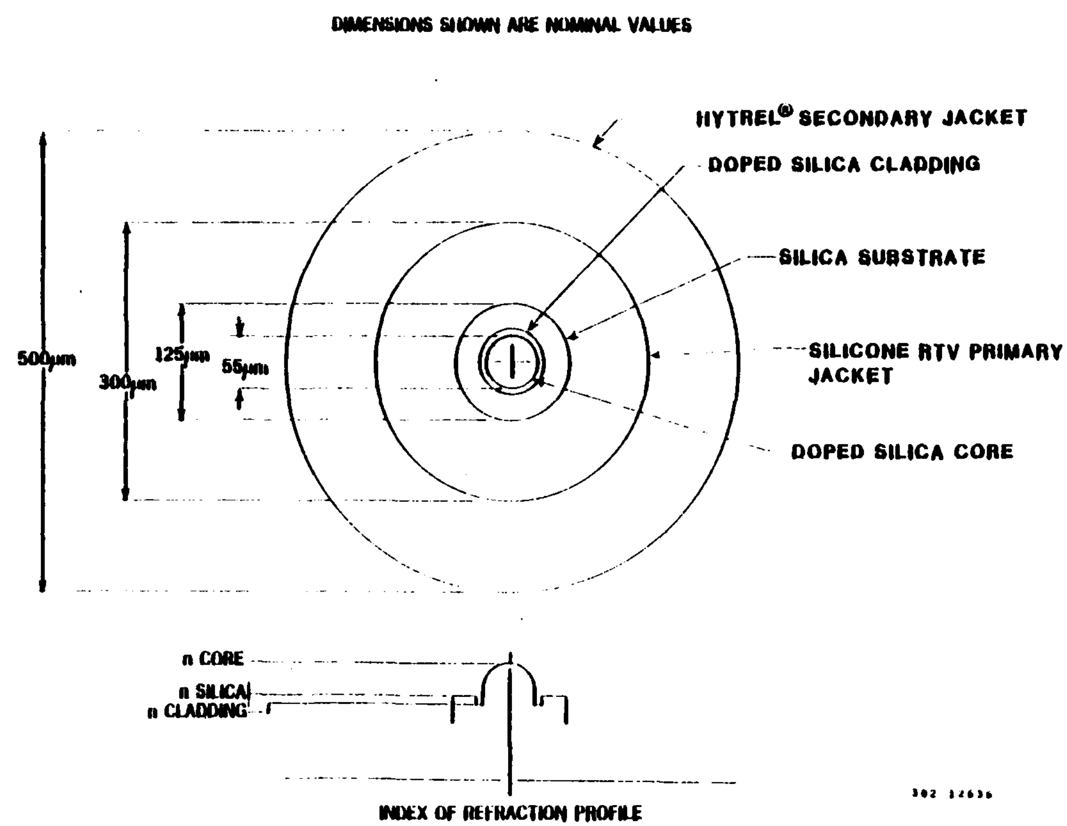

Figure 2-1. Wideband Graded Index Multimode Optical Fiber.

2.1.1 Primary Buffer

A room temperature vulcanizing (RTV) silicone protective coating, Dow Corning Sylgard® 184, is applied by dipcoating to a finished diameter of 300 μm immediately after drawing. This protective coating guards the fibers from any initial handling or foreign substances that may damage or reduce the quality of the product and is compatible with the buffering materials. Sylgard® 184 is used because of the ease in stripping this material.

2.1.2 Secondary Buffer

All fibers have a Hytrel® 7246 buffer layer for additional protection. The layer is tubing extruded to a finished diameter of 0.5 mm. An additional layer is pressure extruded to 1.02 mm to provide the rugged mechanical and environmental performance. All fibers were manufactured between December 1977 and October 1978.

2.1.3 Center Filler

The center filler element of the cable was varied in the three designs as follows:

a. Design 1 - Optical fiber

b. Design 2 - Nylon monofilament

c. Design 3 - Polyurethane (E-80) coated Kevlar® 49 (380 denier)

2.1.4 Polyurethane Inner Jacket

The polyurethane inner jacket is extruded after the cabling operation. The polyurethane used is Roylar® E9-B, a polyether based compound, manufactured by Uniroyal. It is chosen because of its extreme toughness, abrasion resistance, low temperature flexibility, resistance to hydrolysis, fungus resistance, and excellent stability to atmospheric conditions. This jacket supplies support for the fiber making up the cable core and provides a buffer layer between the fiber and Kevlar® reducing abrasion.

2.1.5 Kevlar® Strength Member

Kevlar® 49 has been chosen as the strength member for this application because of its strength versus weight and durability. A total of 18 yarns (1420 denier) is applied helically with a 10.1 cm (4.0 in) lay length. The lay length was selected to be greater than that of the fibers to ensure that the Kevlar® takes the tensile load. The strength member will provide 181.8 kg (400 lb) tensile strength at 1% elongation. One percent elongation is the 100 kpsi fiber proof test level.

2.1.6 Polyurethane Outer Jacket

The outer jacket material is identical to the inner jacket. Figures 2-2 through 2-4 show the cable construction for the three PDMs.

2.2 Optical Evaluation

The attenuation and dispersion of the three PDMs were measured with results indicated in Table 2-1. The values are higher than 5.0 dB/km attenuation and 2.0 ns/km dispersion guidelines established for this program. The purpose of the PDMs was to examine various cable geometry and not to strive for best optical characteristics. The optical performance will be further addressed in the exploratory development models (EDMs). The attenuation measurement error due to injection conditions is multiplied on short length samples with error deviation uncertainty. A description of the attenuation and dispersion measurement technique is located in Appendixes A and B.

2.3 Submit PDM Cable Samples

All three PDMs were shipped after completing the optical evaluation.

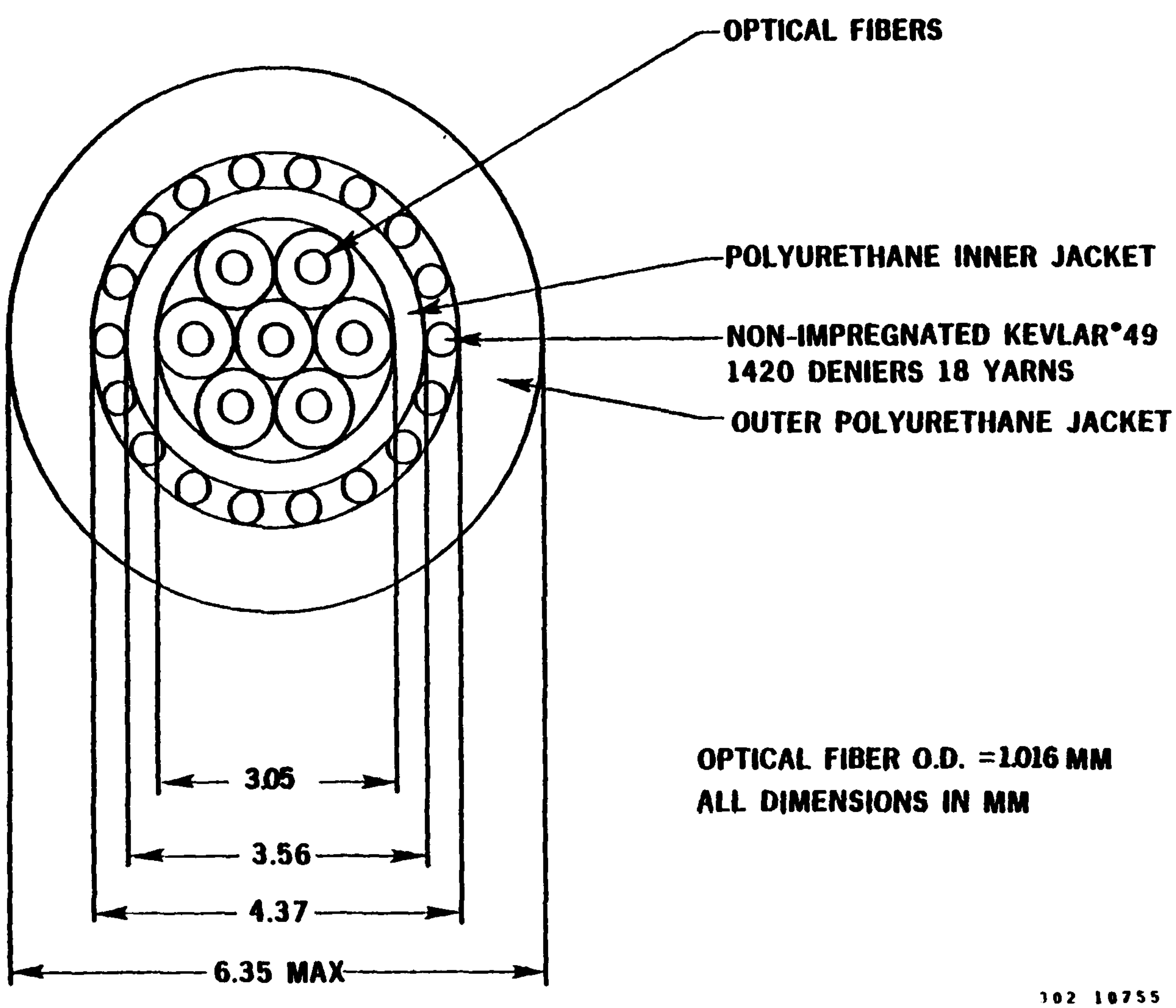

Figure 2-2. Design 1 - Ultra Low Loss Fiber Optic Cable.

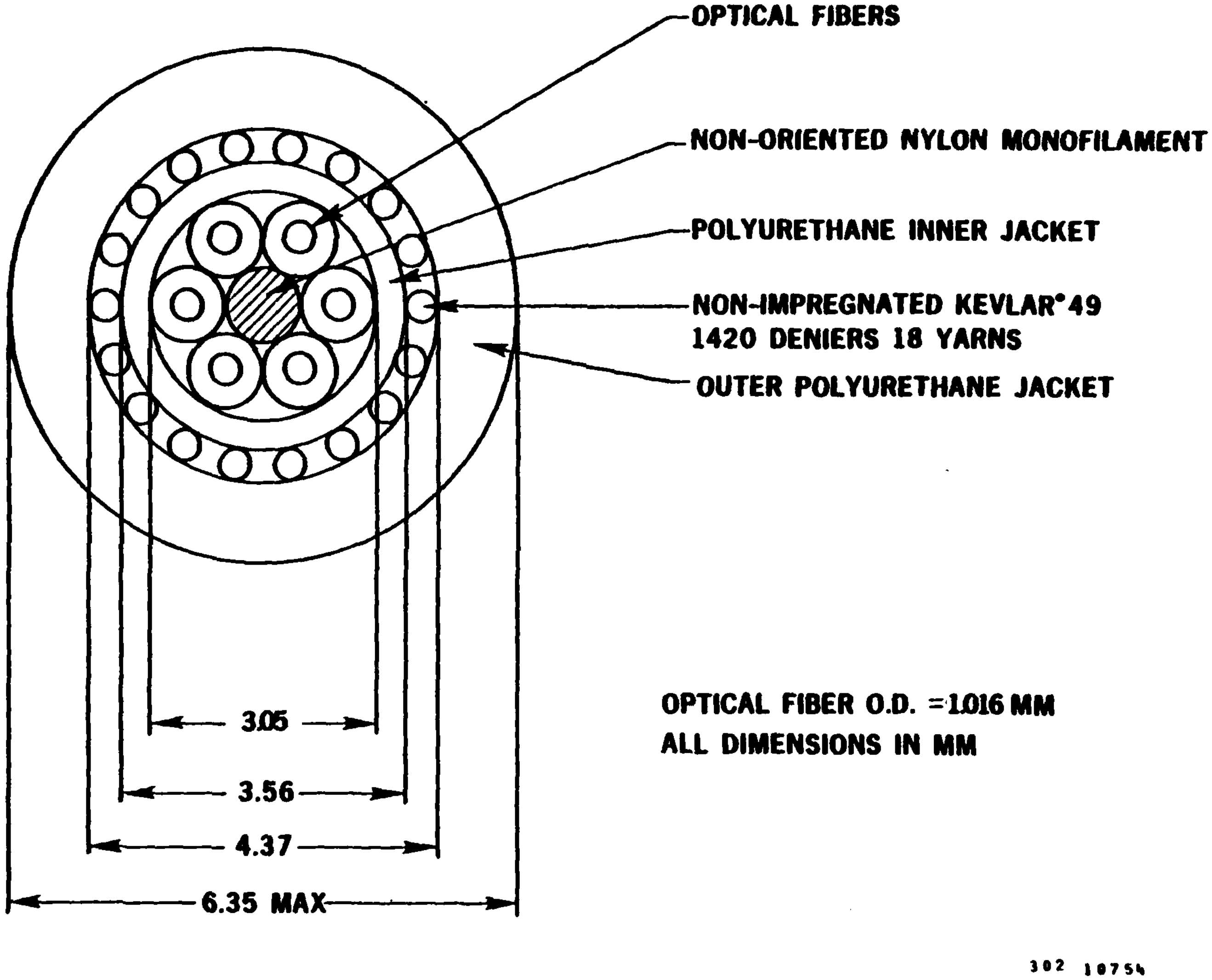

Figure 2-3. Design 2 - Ultra Low Loss Fiber Optic Cable.

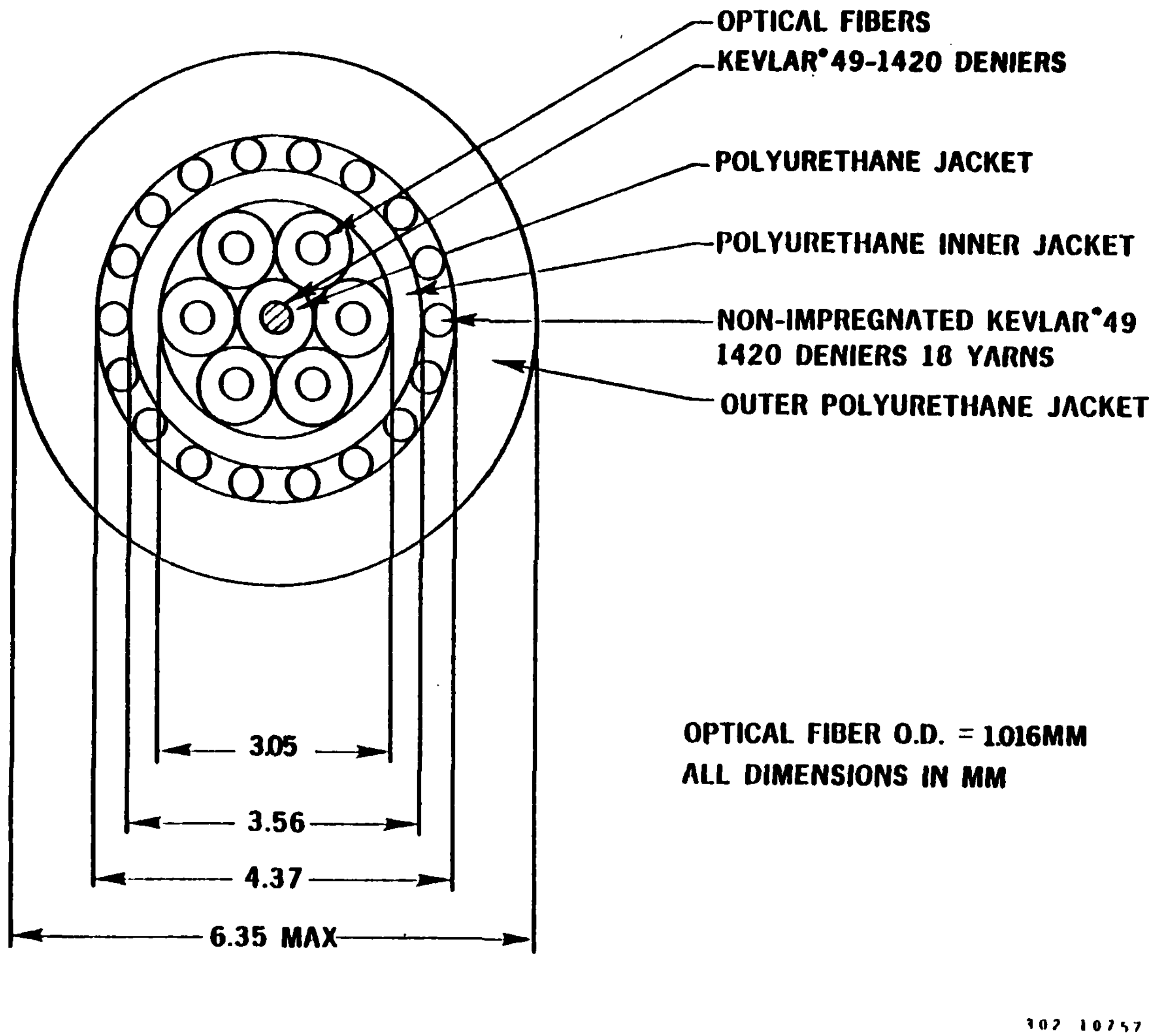

Figure 2-4. Design 3 - Ultra Low Loss Fiber Optic Cable.

Table 2-1. Optical Characteristics of Preliminary Design Models.

Design	Fiber	Attenuation @ 0.85 (dB/km)	Dispersion @ 0.9 (ns/km)
	1	6.22	2.09
1	2	6.33	1.53
(303 m)	3	6.05	2.92
	4	7.31	2.79
	5	6.56	1.53
	6	9.61	4.73
	7	7.29	2.32
2	1	6.11	2.38
(353 m)	2	5.99	3.52
	3	6.56	2.07
	4	5.49	1.31
	5	5.59	1.17
	6	6.39	3.42
3	1	8.35	2.04
(275 m)	2	7.98	2.01
	3	8.38	2.71
	4	8.98	2.10
	5	9.83	2.44
	6	9.05	1.61

3.0 EXPLORATORY DEVELOPMENT MODELS (EDMs)

This section covers the description, construction, and evaluation of the EDM cable samples.

3.1 Test Plan

The EDM cable test plan was submitted and approved for this phase.

3.2 Optical Fibers

All the optical fibers used in these cables are specifically fabricated for the program. The fibers were manufactured between November 1978 and February 1979. The fibers were buffered to 1.02-mm diameter with Hytrel® 7246. All EDM fibers were measured while strung between two drums with a center line distance of 10 m. This evaluation procedure eliminates spooling losses and is a true measure of the intrinsic attenuation. The dimensional measurements for all fibers are listed in Table 3-1.

3.3 EDM Cable Designs

The three cable samples were fabricated in accordance with the cable design plan and have specifications as indicated in Figures 2-2 through 2-4. The EDM cable samples were fabricated using Uniroyal Roylar® E-80 polyurethane for the jacket layers because of its better low temperature flexibility.

Table 3-1. Dimensional Measurements of EDM Cable Samples.

	Core Diameter (μm)		Cladding Diameter (μm)	
Design 1	SOP*	EOP**	SOP*	EOP**
Center	57 x 61	63 x 67	122	135
1) Yellow	57 x 60	57 x 59	127	131
2) Orange	59	59	127	129
3) White	58	59	127	129
4) White	54	50	125	123
5) White	53 x 57	56 x 57	125 x 129	127
6) White	64 x 67	56 x 59	140	125
Design 2				
1) Yellow	53 x 55	56	125	129
2) Orange	56	56	125	125
3) White	57	59 x 56	122 x 127	125
4) White	60 x 61	57 x 59	125 x 129	127 x 129
5) White	52 x 54	57 x 60	122 x 125	119 x 125
6) White	53 x 56	53 x 55	125	127
Design 3				
1) Yellow	56	56 x 58	123 x 125	125
2) Orange	58 x 61	61	123	127
3) White	59	59	125 x 127	127 x 129
4) White	60 x 61	59 x 61	119	125 x 127
5) White	61	62	123	127 x 129
6) White	60 x 61	59	125	127 x 129

*Start of pull, bottom of spool.

**End of pull, top of spool.

3.4 Optical Measurements

The measurement technique used for the PDMs and the EDMs is identical as indicated in Appendix A and B.

3.4.1 Attenuation

Table 3-2 shows the attenuation measured at 0.82-μm wavelength and 0.089-injection NA for each fiber in designs 1, 2, and 3. It also shows the initial fiber attenuation as well as the excess cabling loss. The average attenuation of design 1 was 4.34 dB/km, design 2 was 4.36 dB/km, and design 3 was 4.43 dB/km. The average attenuation increase in all fibers was 0.53 dB/km. Table 3-3 shows the attenuation of the three cable designs at 0.82-, 0.85-, 1.05-, 1.09-, 1.1-, 1.2-, 1.3-, and 1.4-μm wavelengths with 0.089-injection NA and the dispersion at 0.9-μm wavelength.

The statement of work on this contract does not require measurements at wavelengths longer than 1.05 um, but since CORADCOM demonstrated interest in long wavelength transmission, ITT evaluated the cables at 1.09, 1.1, 1.3, and 1.4 um.

The attenuation of the three cable designs was measured with injection NA settings of 0.089, 0.124, 0.176, and 0.243 at 0.82-μm and 1.2-μm wavelengths respectively, as shown in Tables 3-4 and 3-5.

Table 3-2. Attenuation of Ultra Low Loss Cables.

CABLE #	020979 MA II			022679 MA II			030279 MA II		
Cable Design	Design 1 (1091 meters)			Design 2 (1099 meters)			Design 3 (1100 meters)		
Attenuation (dB/km) @ .82 μm	Before*	After**	Δα	Before*	After**	Δα	Before*	After**	Δα
Fiber # Center	4.27	4.80	+.53	—	—	—	—	—	—
1) Yellow	3.59	3.91	+.32	3.76	4.77	+1.01	4.24	5.04	+.80
2) Orange	3.75	3.70	-.05	3.44	3.97	+.53	3.54	3.92	+.38
3) White	3.65	4.04	+.39	4.62	5.12	+.50	3.86	4.33	+.47
4) White	3.52	3.98	+.46	3.57	3.68	+.11	4.22	4.22	+.00
5) White	3.66	4.81	+1.15	4.29	4.39	+.10	3.98	4.26	+.28
6) White	4.14	5.15	+1.01	3.56	4.24	+.68	3.24	4.80	+1.56
Average (dB/km)	3.80	4.34	+.54	3.87	4.36	+.49	3.85	4.43	+.57
Center Element	Fiber			Nylon Monofilament			Polyurethane Jacketed Kevlar		

Average attenuation increase of all fibers (dB/km) was +0.53.

All fibers were measured with 0.089 injection NA.

*Attenuation of Strung Fiber.

**Attenuation of Cabled Fiber.

Table 3-3. Attenuation Versus Wavelength (dB/km).*

Wavelength (μm)	.82	.85	1.05	1.09	1.1	1.2	1.3	1.4	Dispersion @ .9 μm
Fiber #			**Design 1** - Cable 020979-MA-II						1091 m
1) Center	4.80	4.14	2.55	2.46	2.15	1.71	2.22	17.04	.40 ns/km
2) Yellow	3.91	3.41	1.76	1.73	1.65	1.49	1.91	17.58	1.33
3) Orange	3.70	3.31	1.74	1.68	1.57	1.33	1.21	4.17	.45
4) White	4.04	3.36	1.90	1.70	2.20	2.05	2.91	18.75	1.34
5) White	3.98	3.51	1.81	1.64	1.65	1.35	1.36	3.64	1.17
6) White	4.81	4.45	2.76	2.74	2.30	2.06	2.02	4.17	.50
7) White	5.15	4.55	2.56	2.36	1.95	1.51	1.78	17.31	.57
			Design 2 - Cable 022679-MA-II						1099 m
1) Yellow	4.77	4.30	3.07	3.10	2.96	2.74	2.69	8.85	.47 ns/km
2) Orange	3.97	3.27	2.00	1.82	1.58	1.32	1.27	4.47	.50
3) White	5.12	4.33	2.45	2.26	1.67	1.44	1.6	15.9	1.41
4) White	3.68	3.04	1.65	1.48	1.40	1.19	1.44	13.44	.47
5) White	4.39	3.88	2.30	2.18	2.62	2.36	2.52	14.07	.32
6) White	4.24	3.75	2.16	2.03	2.14	4.62	2.03	9.45	.70
			Design 3 - Cable 030279-MA-II						1100 m
1) Yellow	5.04	4.54	3.04	2.62	2.78	2.51	2.41	11.45	.30 ns/km
2) Orange	3.92	3.51	1.88	1.71	1.59	1.40	1.58	12.71	.30
3) White	4.33	3.83	2.02	2.07	1.71	1.50	1.62	10.69	.11
4) White	4.22	3.91	2.24	2.04	2.11	1.87	1.90	10.44	.26
5) White	4.26	3.86	2.29	2.13	1.89	1.71	1.89	13.44	.33
6) White	4.80	4.41	2.74	2.59	2.72	2.55	2.68	10.33	.66

*Measured at 0.089 injection NA.

Table 3-4. Attenuation Versus Injection NA (Wavelength 8.2 μm).

Cable Design	Fiber #	Injection NA			
		.089	.124	.176	.243
1	1) Center	4.80 dB/km	4.75 dB/km	5.52 dB/km	5.95 dB/km
	2) Yellow	3.91	3.96	4.48	4.71
	3) Orange	3.70	4.00	3.88	3.96
	4) White	4.04	3.97	4.56	4.91
(1091 meters)	5) White	3.98	3.77	3.91	3.78
	6) White	4.81	4.82	4.98	5.20
	7) White	5.15	5.39	5.90	6.20
2	1) Yellow	4.77	4.94	4.94	5.23
	2) Orange	3.97	4.13	4.11	4.19
	3) White	5.12	5.25	5.26	5.45
(1099 meters)	4) White	3.68	3.85	4.01	4.20
	5) White	4.39	4.36	4.48	4.21
	6) White	4.24	4.41	4.50	4.64
3	1) Yellow	5.04	5.29	5.71	6.25
	2) Orange	3.92	4.04	4.24	4.53
	3) White	4.33	4.63	4.71	5.30
	4) White	4.22	4.52	4.66	5.10
(1100 meters)	5) White	4.26	4.48	4.73	5.24
	6) White	4.80	4.95	5.28	5.51

Table 3-5. *Attenuation Versus Injection NA*
(Wavelength 1.20 μm).

Cable Design	Fiber #	Injection NA			
		.089	.124	.176	.243
1 (1091 meters)	1) Center	1.71 dB/km	1.99 dB/km	2.57 dB/km	3.04 dB/km
	2) Yellow	1.49	1.41	1.81	2.12
	3) Orange	1.33	1.24	1.55	1.70
	4) White	2.05	2.15	2.34	2.68
	5) White	1.35	1.38	1.49	1.63
	6) White	2.06	2.06	2.23	2.65
	7) White	1.51	1.40	1.76	2.15
2 (1099 meters)	1) Yellow	2.74	2.73	3.02	3.37
	2) Orange	1.32	1.37	1.60	1.68
	3) White	1.44	1.43	1.65	1.89
	4) White	1.19	1.14	1.45	1.73
	5) White	2.36	2.51	2.76	2.92
	6) White	4.62	4.78	5.03	5.23
3 (1100 meters)	1) Yellow	2.51	2.75	3.07	3.32
	2) Orange	1.40	1.51	1.71	2.01
	3) White	1.50	1.61	1.80	2.08
	4) White	1.87	2.09	2.41	2.84
	5) White	1.71	1.87	2.21	2.44
	6) White	2.55	2.72	2.94	3.11

The attenuation at each of the remaining wavelengths was measured at an injection NA of 0.089. The single NA was selected to avoid changing injection NA conditions at each wavelength, thereby possibly introducing input variation between the short and long length measurements. While the 0.089-injection NA is substantially less than the NA of the fiber, Kaiser[1] has reported that low NA injection of similar graded index fibers results in a modal distribution closer to "steady state" conditions than that achieved with higher injection NAs. Further, the 0.089 NA is selected to avoid excess transient losses introduced by modal over-excitation in short lengths of graded index fibers. These leaky modes may be propagated through the borosilicate cladding layer.

Once the output through the long length was measured at the specified wavelengths, the fiber was cut at a distance of 1 m from the injection end. A new end was prepared on the output end of the reference length and the measurement repeated for the short length.

[1]P. Kaiser, "NA-Dependent Spectral Loss Measurements of Optical Fibers," Transactions of the Inst of El and Comm Eng, Japan, March 1978.

3.4.2 Attenuation Results

The data in Table 3-2 indicates that at least one fiber in each design has a high cabling loss ($\approx$1.0 dB/km). These excess cabling losses are attributed to fiber bend sensitivity which is being examined and characterized.

3.4.3 Numerical Aperture

The 90% power point NA was measured, and it is reported in Table 3-6. The 90% power NA is determined by first measuring the fiber output close to the detector. Then the fiber is moved away from the detector, reducing the detector field of view. At the point where the output drops 10%, the detector-fiber separation is recorded and the cone angle containing 90% of the power calculated. The large variation in results on some fibers is caused by diameter fluctuations along the fiber length.

3.5 Mechanical Tests

The EDM cables were subjected to the mechanical tests of MIL-C-13777, paragraphs 3.7.1 and 3.7.2. These tests were performed at ambient temperatures of +21°C, -54°C, and +71°C.

Table 3-6. Numerical Aperture (90% Power).

Fiber #	Cable Design 1	Cable Design 2	Cable Design 3
1) Yellow	.21	.19	.19
2) Orange	.19	.20	.20
3) White	.19	.20	.21
4) White	.20	.21	.20
5) White	.17	.21	.21
6) White	.20	.20	.15
Center	.20	--	--

Design 1 - 1091 meters, optical fiber center element.

Design 2 - 1099 meters, nylon monofilament center element.

Design 3 - 1100 meters, polyurethane coated Kevlar® center element.

3.5.1 Impact Resistance

This test was performed in accordance with paragraph 3.7.2 of MIL-C-13777F at ambient temperatures of +21°C, +71°C, and -54°C. The results are shown in Table 3-7.

The 100% survivability goal was achieved in all three designs at +21°C and +71°C. Designs 2 and 3 also met this goal at -54°C. Cable design 1 had one broken fiber in one of the six samples; this brought the percentage of surviving fibers to 97.6% after 200 impacts at a load of 0.415 kg-m when tested at -54°C.

3.5.2 Bend Test

The bend test was performed at +21°C, +71°C, and -54°C, in accordance with MIL-C-13777, paragraph 3.7.2. Table 3-8 shows the performance of the cabled fibers during the test. Continuity was monitored during the test with no fiber failures observed.

The goal of 100% surviving fibers after 2000 cycles was achieved with all three cable designs.

Table 3-7. Impact Resistance.

Cable Design	Temperature (C°)	# of Cabled Fibers	Transmitting/ Broken	% Surviving Fibers
1	+21	42	42/0	100
	+71	42	42/0	100
	-54	42	41/1	97.6
2	+21	36	36/0	100
	+71	36	36/0	100
	-54	36	36/0	100
3	+21	36	36/0	100
	+71	36	36/0	100
	-54	36	36/0	100

Design 1 - Optical fiber center element.

Design 2 - Nylon monofilament center element.

Design 3 - Polyurethane coated Kevlar® center element.

Table 3-8. Bend Test.

Cable Design	Temperature (C°)	# of Cabled Fibers	Transmitting/ Broken	% Surviving Fibers
1	+21	21	21/0	100
	+71	21	21/0	100
	-54	21	21/0	100
2	+21	18	18/0	100
	+71	18	18/0	100
	-54	18	18/0	100
3	+21	18	18/0	100
	+71	18	18/0	100
	-54	18	18/0	100

Design 1 - Optical fiber center element.

Design 2 - Nylon monofilament center element.

Design 3 - Polyurethane coated Kevlar® center element.

3.5.3 Twist Test

The test was performed at +21°C, +71°C, and -54°C in accordance with MIL-C-13777, paragraph 3.7.2.

Table 3-9 shows the performance of each cable design. Continuity was monitored during the test with only one fiber failure at room temperature on design 2 (nylon monofilament center).

Designs 1 and 3 met the 100% survivability goal at all temperatures. There was one fiber break after 1480 twist cycles on design 2 when tested at room temperature. This cable design met the goal of 100% survivability at +71°C and -54°C.

The top sheave of the twist test apparatus consisted of two adjustable plates. This sheave arrangement was not satisfactory and caused undue damage to the cable jacket. Due to schedule limitations, it was not possible to replace it. It was suspected that this arrangement was responsible for the fiber break.

Table 3-9. Twist Test.

Cable Design	Temperature (C°)	# of Cabled Fibers	Transmitting/ Broken	% Surviving Fibers
1	+21	21	21/0	100
	+71	21	21/0	100
	-54	21	21/0	100
2	+21	18	17/1	94
	+71	18	18/0	100
	-54	18	18/0	100
3	+21	18	18/0	100
	+71	18	18/0	100
	-54	18	18/0	100

Design 1 - Optical fiber center element.

Design 2 - Nylon monofilament center element.

Design 3 - Polyurethane coated Kevlar® center element.

Despite this broken fiber, the cable managed to have 94% of its tested fibers continuous after 2000 cycles. It is felt that by using a proper sheave, all cable designs at all temperatures will pass this test without fiber breakage.

3.5.4. Tensile Load Test

Data on long term effects of the static load is obtained by applying a tensile load to the cable for a period of 48 hours, during which time the transmission through the fibers is monitored.

Two samples of design 3 were tested for effects of tensile load on fiber attenuation. Periodic attenuation monitoring was used. The cable tested gage length was 6 m.

The cable elongation with a 6-m half loop setup exceeded the extension range of the tensile load equipment due to rotation of the mandrel. To overcome this problem, a complete loop was used (approximately 12.5-m gage length) during this and the remaining tests.

The first sample of design 2 was tested using manual data acquisition. The remaining three tests were performed using an eight-channel strip chart recorder. This enabled continuous monitoring of differential attenuation throughout

the 48-hour test period. All fibers are monitored for attenuation change and not absolute values on this station.

Tables 3-10, 3-11, 3-12, 3-13, 3-14, and 3-15 show the test results of designs 1, 2, and 3, respectively.

These results indicate that the residual effects of long term tensile load on the optical performance of designs 1, 2, and 3 are negligible. The visual inspection indicated that the strength members and the optical core had some position shifting; however, after the load was released, they slowly returned to their original positions.

Table 3-10. Tensile Load Test - Differential Attenuation (dB).

Cable Design 1 Sample #1

Time	Load	Fiber #					
		1	2	3	4	5	6
0 min	0 kg	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
1	182	.095	.053	.109	.036	.033	.117
2	184	.095	.065	.109	.044	.033	.137
7	186	.095	.053	.109	.044	.033	.139
12	184	.081	.041	.087	.027	.014	.099
32	182	.053	.029	.065	.018	.014	.099
1 hour	193	.067	.041	.087	.027	.033	.119
2	193	.081	.065	.109	.062	.052	.139
6	183	.053	.090	.065	.088	.168	.179
10	180	.067	.126	.087	.124	.188	.179
12	182	.067	.090	.065	.079	.110	.179
24	193	.039	.065	.043	.053	.033	.159
36	191	.067	.114	.065	.062	-.005	.179
48	184	.067	.102	.087	.053	-.043	.179
49	0	-.016	.029	0	.018	-.099	.039

Table 3-11. Tensile Load Test - Differential Attenuation (dB).

Cable Design 1 **Sample # 2**

Time	Load	Fiber #					
		1	2	3	4	5	6
0 min	0 kg	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
1	207	0	0	.0	.02	0	-.01
2	207	-.04	-.04	-.04	-.02	-.04	-.04
3	207	.04	-.04	-.04	-.02	-.04	-.04
1 hour	207	.08	-.03	-.03	-.01	.08	-.03
3	207	.17	-.05	.06	-.03	.17	.06
5	207	.17	-.05	.06	-.03	.17	.06
7	207	.17	-.05	.06	-.03	.17	.06
12	207	.06	-.06	.06	-.15	-.05	.06
16	207	.03	-.08	.03	-.18	-.08	-.08
18	147	.06	-.05	.06	-.15	-.15	-.05
20	191	.06	-.15	.06	-.10	-.15	-.05
22	190	.06	-.05	.06	-.03	0	0
25	205	.17	-.05	.06	-,03	.12	BREAK
30	205	.20	-.03	.09	0	.20	--
36	193	.17	-.05	.06	-.15	-.05	--
40	193	.19	-.11	.07	-.13	-28	--
43	193	.18	-.05	.18	-.18	-.40	--
45	193	.08	-.16	.08	-.11	-.39	--
48	193	.11	-.14	.11	-.08	-.25	--
51	0	.16	-.05	.16	-.16	.16	--

Table 3-12. Tensile Load Test - Differential Attenuation (dB).

Cable Design 2 Sample # 1

Time	Load	Fiber #					
		1	2	3	4	5	6
0 min	0 kg	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
1	188	.11	.11	0	0	0	0
2	188	.11	.11	0	0	0	0
3	188	.11	.11	0	0	0	0
2 hour	188	.05	0	-0.1	0	0	-.05
3	188	.01	.01	-.25	.01	.01	-.1
6	188	.11	0	-.21	.11	.11	0
10	188	.11	.11	-.21	.11	.11	0
13	188	.17	.17	-.21	.17	.22	.05
15	188	.06	.06	-.32	0	-.05	-.05
20	188	.21	.16	-.22	.21	.33	.10
22	188	.21	.21	-.22	.21	.39	.21
24	188	.23	0	-.32	.23	.35	.23
26	188	.17	-.05	-.27	.21	.28	.28
29	188	.11	-.11	-.31	.11	.11	.34
42	188	.24	-.12	-.23	.24	.12	.18
51	184	.37	-.12	.17	.37	.30	.50
60	184	.18	0	-.29	.18	0	.31
69	193	.12	0	-.23	.12	-.06	.12
89	193	.25	0	-.23	.25	-.06	.25
93	0	.19	-.06	-.30	.32	.12	.25

Table 3-13. Tensile Load Test - Differential Attenuation (dB).

Cable Design 2 Sample #2

Time	Load	Fiber #					
		1	2	3	4	5	6
0	0	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
1 min	200 kg	.22	.29	.22	.11	.06	- .11
2	200	.22	.24	.23	.12	.07	- .40
3	200	.22	.24	.23	.12	.07	- .30
5	200	.29	.24	.23	.12	.07	- .40
2 hour	198	.23	.18	.12	.23	.18	-2.77*
4	198	.23	.30	.12	.35	.17	-2.65
9	198	.31	.37	.14	.54	.26	-2.46
11	160	.22	.34	.11	.56	.16	**
13	182	.22	.28	.11	.56	.11	**
20	182	.12	.23	.01	.58	.01	**
24	182	.16	.28	.05	.56	.06	-2.73
26	182	.13	.30	Break	.59	.13	-2.76
33	182	.17	.30	-	.60	.11	-2.77
37	182	.12	.19	-	.61	-.10	-2.88
42	182	.22	.29	-	.71	-.12	-2.79
44	182	.17	.29	-	.71	-.11	-2.89
46	182	.16	.21	-	.64	-.14	-2.88
49	182	.23	.30	-	.60	-.05	-2.89
51	186	.29	.30	-	.60	0	-2.65
53	0	.18	.14	-	.53	-.03	-2.75

* Decrease in loss is believed connector related
** Problems with strip chart recorder

Table 3-14. Tensile Load Test - Differential Attenuation (dB).

Cable Design 3 Sample #1

Time	Load	Fiber #					
		1	2	3	4	5	6
-20 min	0	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
-15	0	.04	.05	.02	.08	-.02	.05
- 5	23 kg	.04	.07	.03	.08	-.02	.07
0	182	.05	.11	.06	.17	0	.11
5	182	.05	.10	.04	.17	-.01	.11
15	213	.05	.10	.05	.16	-.02	.11
43	186	.05	.12	.05	.18	-.01	.12
1 hour	182	.04	.13	.05	.18	-.02	.14
2	182	.02	.15	.03	.20	-.03	.17
4	195	.01	.14	.03	.20	-.04	.16
8	191	0	.16	.05	.25	-.05	.21
13	186	.01	.08	.03	.18	-.04	.17
19	209	.03	.06	.06	.13	-.01	.14
31	184	.01	.12	.06	.28	-.03	.21
46	182	.03	.05	.06	.13	0	.13
46	0	.02	.05	.05	.11	-.02	.12

Table 3-15. Tensile Load Test - Differential Attenuation (dB).

Cable Design 3 Sample #2

Time	Load	Fiber #					
		1	2	3	4	5	6
-20 min	0	0 dB	0 dB	0 dB	0 dB	0 dB	0 dB
-10	23 kg	-.02	-.02	0	.01	-.01	.02
- 5	91	-.01	-.02	0	.04	0	.02
0	182	-.01	0	.02	.07	.01	.04
1	182	-.02	0	.01	.05	.01	.05
5	182	-.01	.01	.02	.07	.01	.05
10	182	-.02	.01	.01	.07	.01	.05
20	182	-.02	.01	.01	.07	.01	.06
30	273	-.03	.01	.02	.07	.01	.08
1 hour	236	0	.02	.02	.08	.02	.19
2	186	-.03	-.01	0	.07	-.01	.25
4	259	-.02	.02	.03	.10	.01	.33
8	218	-.04	-.04	.02	.05	-.04	.45
16	204	-.04	-.05	.02	.05	-.04	.54
20	204	-.05	-.05	.02	.08	-.04	.55
24	200	.13	-.05	.03	.08	-.05	.58
48	193	.20	-.07	.05	.14	-.04	.60
50	186	.13	-.05	.05	.61	.04	.60
50	0	.13	-.05	.05	.20	.06	.62
52	0	.13	-.09	.05	.13	.01	.63

3.6 EDM Cable Environmental Tests

The environmental tests include:

a. Temperature/humidity test

b. Temperature shock test

c. Vibration test

Tables 3-16 through 3-18 summarize the performance of the EDM cables. Attenuation at each wavelength was measured with 0.089 injection NA.

It was found that the cables were sensitive to low temperature, which greatly increased the optical attenuation of the cabled fibers. This was an unexpected problem because a number of cables (designed for commercial telecommunication applications) had been tested at low temperature (-40°C and -50°C) with loss increases from 1 to 1.5 dB/km.

Figures 3-1, 3-2, and 3-3 depict the performance of the fibers of the EDM cables when exposed to temperatures from -65°C to +65°C. Fiber identification was not recorded during the test. All future tests will include identification to correlate performance with fiber data.

Table 3-16. Attenuation of Cable Design 1 Before and After Environmental Testing (dB/km).

	Fiber #1 (Yellow)				Fiber #2 (Orange)				Fiber #3			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (658 m)	3.62	3.30	1.68	1.62	3.48	3.27	1.55	1.31	4.13	3.66	2.10	2.32
After Temperature/humidity Test	4.08	-	-	-	4.20	-	-	-	5.08	-	-	-
After Temperature Shock Test	3.67	3.13	1.25	1.47	4.19	3.70	1.88	1.98	5.19	4.52	2.79	2.76
After Vibration Test	4.24	3.67	2.15	1.07	4.21	3.75	2.10	1.55	4.87	4.26	2.71	2.53
Δ Attenuation (Original vs Final)	.62	.37	.47	.55	.73	.48	.55	.24	.74	.60	.61	.21

	Fiber #4				Fiber #5				Fiber #6			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (658 m)	4.01	3.60	1.91	1.89	4.61	4.04	2.67	2.54	5.51	4.47	2.78	2.83
After Temperature/humidity Test	5.14	-	-	-	5.52	-	-	-	5.84	-	-	-
After Temperature Shock Test	5.10	4.66	3.29	2.83	5.40	4.76	3.13	3.05	5.69	5.07	2.98	2.88
After Vibration Test	5.55	4.95	3.38	2.93	5.74	5.10	3.72	3.21	5.55	4.95	3.38	2.93
Δ Attenuation (Original vs Final)	1.54	1.35	1.47	1.04	1.13	1.06	1.05	.67	.04	.48	.60	.10

Table 3-17. Attenuation of Cable Design 2 Before and After Environmental Testing (dB/km).

	Fiber #1 (Yellow)				Fiber #2 (Orange)				Fiber #3			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (678 m)	5.35	4.66	3.58	3.44	4.14	3.58	2.22	2.13	5.05	4.42	2.22	2.10
After Temperature/humidity Test	6.00	-	-	-	5.48	-	-	-	5.62	-	-	-
After Temperature Shock Test	6.68	6.33	5.10	4.85	4.66	4.34	2.88	2.78	5.44	4.64	1.95	2.20
After Vibration Test	7.05	6.75	5.45	5.06	5.21	4.80	3.21	2.84	5.54	4.91	2.87	2.42
Δ Attenuation (Original vs Final)	1.70	2.09	1.87	1.62	1.07	1.22	.99	.71	.49	.49	.65	.20

	Fiber #4				Fiber #5				Fiber #6			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (678 m)	3.68	3.47	1.48	1.43	4.34	4.01	2.44	2.25	4.79	4.21	2.87	2.81
After Temperature/humidity Test	3.84	-	-	-	5.24	-	-	-	5.64	-	-	-
After Temperature Shock Test	3.98	3.41	2.05	1.85	4.57	4.02	2.52	2.30	5.72	5.13	3.58	3.52
After Vibration Test	3.89	3.42	1.91	1.78	5.09	4.60	2.87	2.76	6.18	5.60	4.28	3.77
Δ Attenuation (Original vs Final)	.21	-.05	.43	.35	.74	.59	.43	.51	1.39	1.39	1.41	.96

Table 3-18. Attenuation of Cable Design 3 Before and After Environmental Testing (dB/km).

	Fiber #1 (Yellow)				Fiber #2 (Orange)				Fiber #3			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (666 m)	5.24	4.49	3.07	3.52	3.84	3.29	1.85	1.82	4.49	4.41	2.39	2.23
After Temperature/humidity Test	5.63	-	-	-	4.51	-	-	-	5.57	-	-	-
After Temperature Shock Test	4.98	4.30	2.97	2.66	4.41		2.62	2.36	4.66	4.44	2.68	2.46
After Vibration Test	5.15	4.65	2.98	3.01	5.16	4.52	2.72	2.40	5.03	4.51	3.00	2.90
Δ Attenuation (Original vs Final)	-.09	.16	-.09	-.051	1.32	1.23	.87	.58	.54	.10	.61	.67

	Fiber #4				Fiber #5				Fiber #6			
Wavelength (μm)	.82	.85	1.05	1.09	.82	.85	1.05	1.09	.82	.85	1.05	1.09
Original Evaluation After Cut to Length (666 m)	4.36	3.77	2.28	2.16	4.50	3.79	2.53	2.39	4.55	3.68	2.35	2.24
After Temperature/humidity Test	5.55	-	-	-	4.96	-	-	-	5.58	-	-	-
After Temperature Shock Test	5.22	4.73	2.90	3.02	5.18	4.20	2.39	2.55	5.51	4.74	3.32	3.16
After Vibration Test	5.85	5.48	3.81	3.76	5.03	4.54	2.92	2.92	5.92	5.50	3.71	3.25
Δ Attenuation (Original vs Final)	1.49	1.77	1.53	1.60	.53	.75	.39	.53	1.37	1.82	1.36	1.01

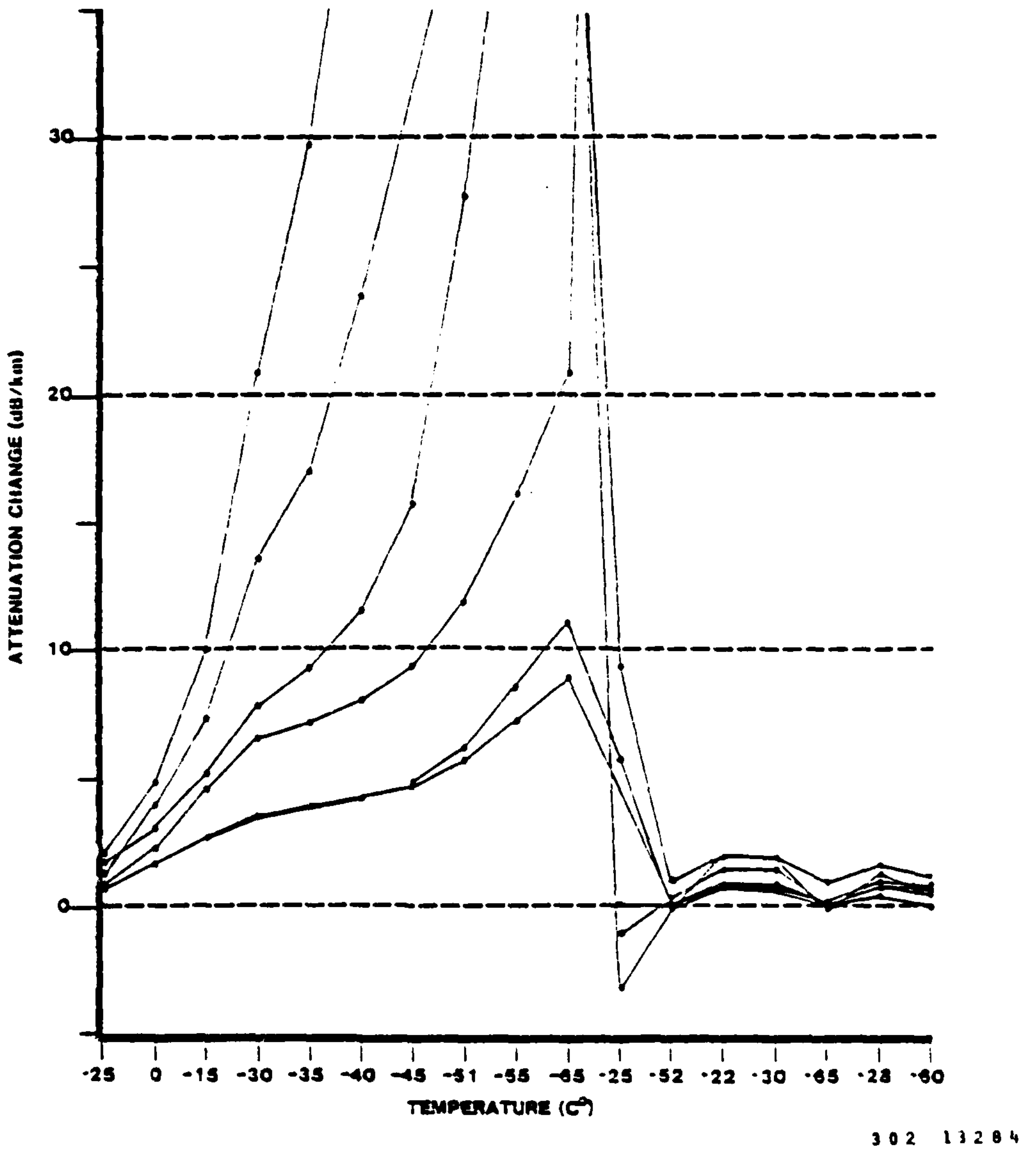

Figure 3-1. Attenuation Versus Temperature Test (Low Temperatures), Design 1.

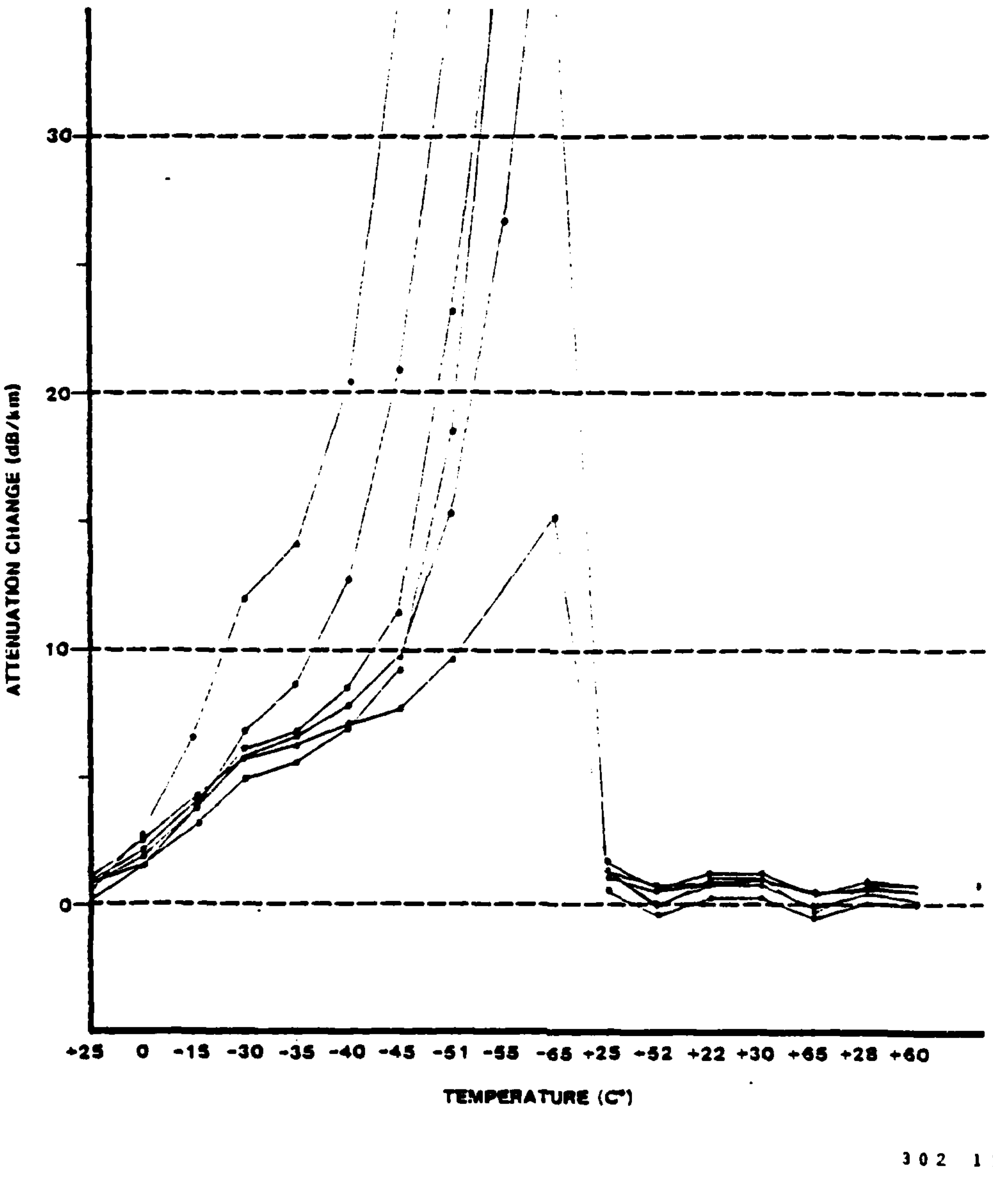

Figure 3-2. Attenuation Versus Temperature Test (Low Temperatures), Design 2.

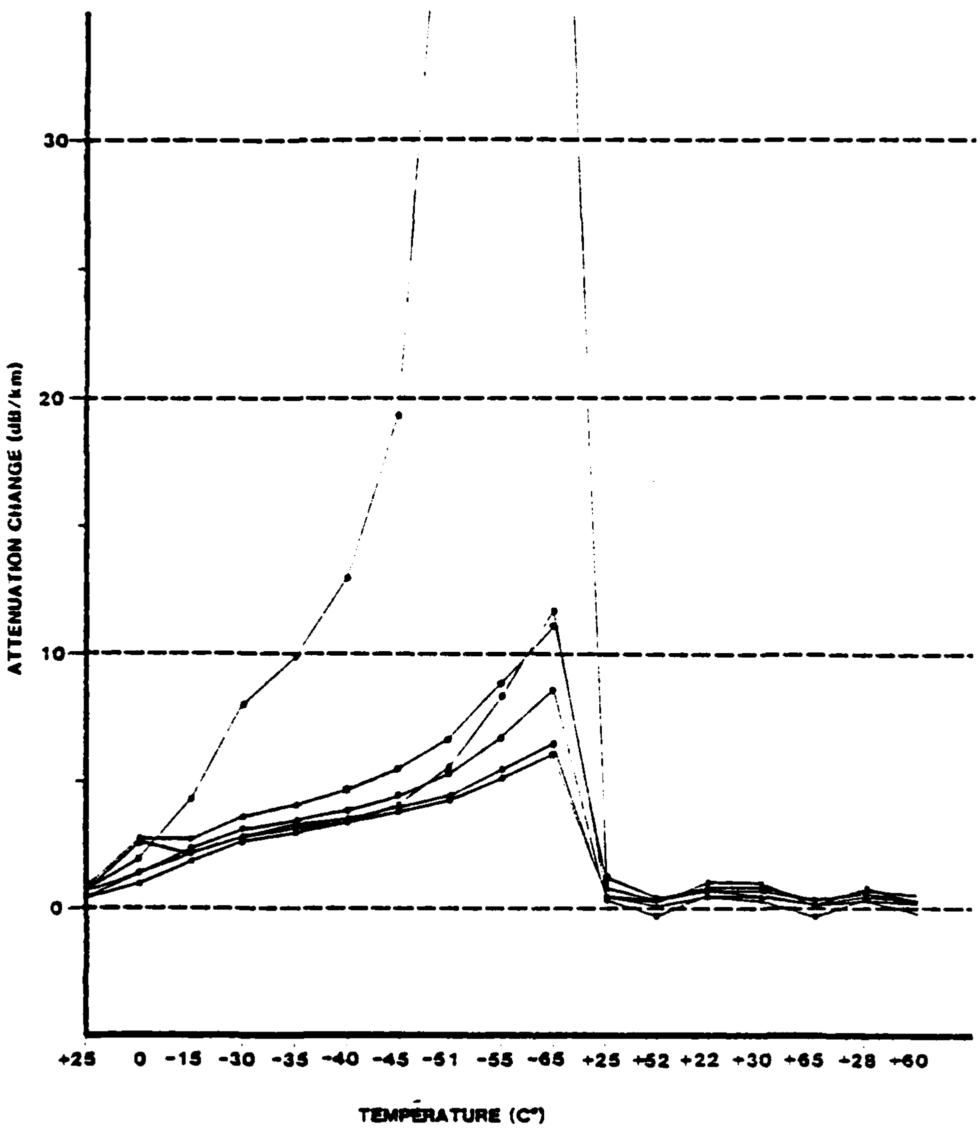

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Figure 3-3. Attenuation Versus Temperature Test (Low Temperatures), Design 3.

The major difference between the telecom cables and the ultra low loss cables was the grade of polyurethane used for the jackets (Roylar® E-9 and Roylar® E-80 respectively) and the buffered fiber diameter of 0.94 mm on telecom cables versus 1.02 mm on ultra low loss cables. It was decided to make another sample cable length of design 1 using Roylar® E-9. The low temperature performance was equally poor.

Two cables were designed in an attempt to incorporate some features of the telecommunication cables into the ultra low loss design. These are shown in Figures 3-4 and 3-5 and were labeled designs 4 and 5, respectively.

These cables were fabricated using some of the same batch fibers as previously used, with similar results noted at low temperatures. At this point, it was suspected that the problem might be a fiber problem and not due to the cable design. Therefore, several fibers fabricated for the ultra low loss contract and a few fibers from the regular production inventory were exposed to low temperatures. Surprisingly, only the ultra low loss fibers performed poorly, indicating that either the

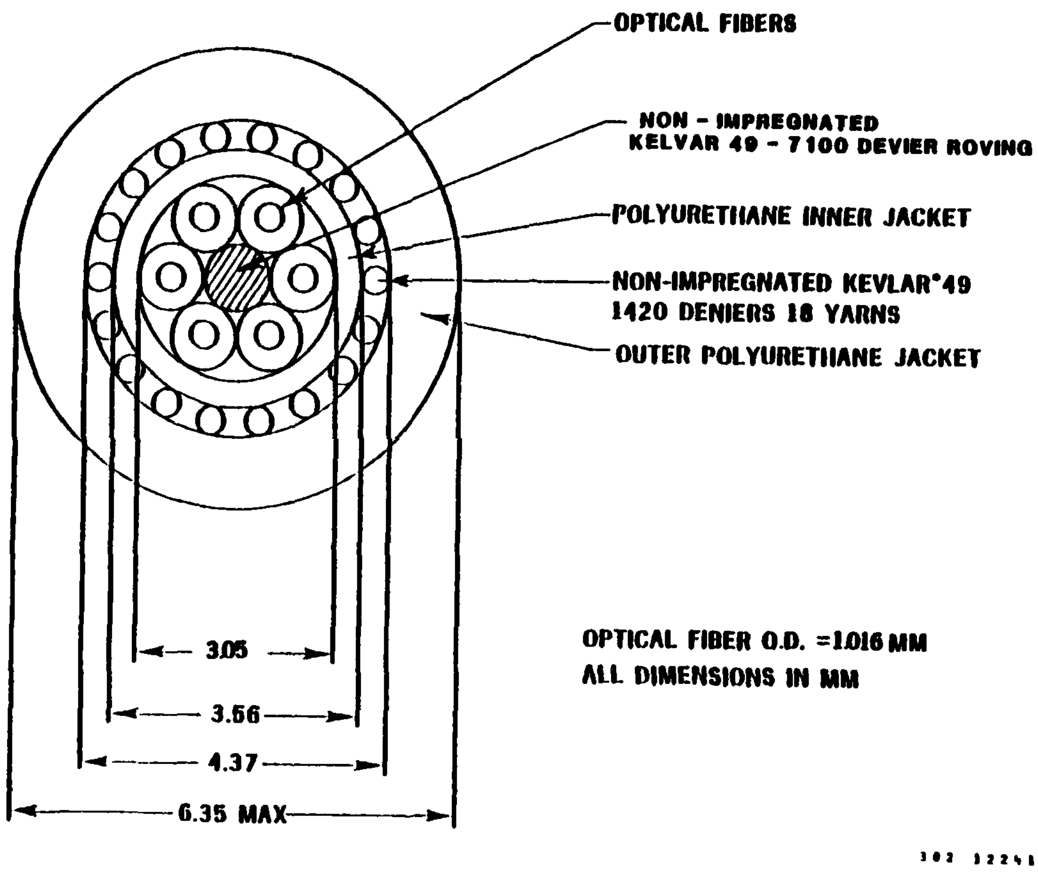

Figure 3-4. Design 4, Ultra Low Loss Fiber Optic Cable.

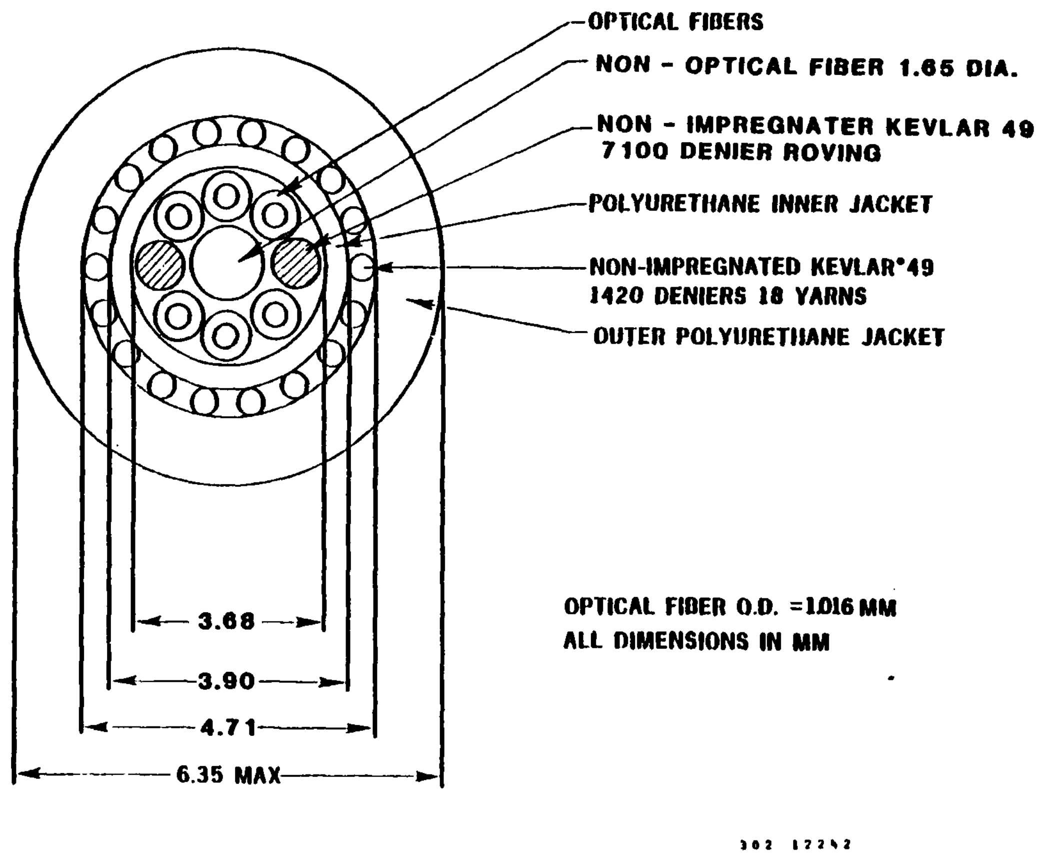

Figure 3-5. Design 5, Ultra Low Loss Fiber Optic Cable.

fiber dopants or fabrication had a major effect. The other variation was the fiber buffer diameter of 0.94 mm versus 1.02 mm on ultra low loss fibers.

An investigation was begun to determine the reason for this effect. This investigation will examine all aspects of the ultra low loss fiber fabrication to find any variables from standard production or trace the individual fiber performance at low temperature for the cause.

3.6.1 Fungus Test

This test was performed by Aerospace Research Corporation. Their test report indicates that there was a very light growth on the surface of all six cables. These samples were returned to ITT EOPD where this light growth was verified by observation under the microscope.

A sample of the tested cable was delivered to Uniroyal Chemical, the company which supplied the jacketing material. Uniroyal's conclusion was that the polyurethane polymer is a nonnutrient material; however, a very small amount of a

processing aid was responsible for this small amount of fungus growth. It was also the company's conclusion that the integrity of the jacket was not jeopardized by this light fungus growth.

Uniroyal indicated that two approaches may be followed if it is determined that this fungus growth is unacceptable: (a) eliminate the processing aid acting as a nutrient, or (b) add a fungicide.

At this time, ITT EOPD is not recommending either approach until it is determined that further action is justified.

4.0 CONNECTOR DEVELOPMENT

This program requires the development of cable assemblies and bulkhead receptacles. The cable assemblies will include hermaphroditic plugs compatible with the bulkhead receptacles, the six-channel cable design, and the fiber characteristics. To accomplish the connector design effort, a subcontract was awarded to the ITT Cannon Electric Division.

4.1 Cable/Connector Interaction

In order to meet the cable assembly objectives, an iterative trade-off process between cable requirements and parameters and connector requirements is necessary. The identification of the fiber/cable parameters most heavily affecting connector design and performance has been tentatively determined as follows:

a. Fiber diameter (close tolerances and roundness)

b. Fiber core diameter (concentricity and tolerances)

c. Fiber NA

d. Fiber bend loss sensitivity

e. Fiber rigidity (buffer material)

f. Fiber torsional modulus

g. Fiber strippability

h. Cable strength member design

i. Cable jacket material

j. Injection NA of the fiber

These parameters must be considered in developing a suitable connector fiber alignment concept as well as the necessary protective and sealing features required in this program. In total, seven cable designs were fabricated and evaluated in order to effect a compromise between fiber/cable requirements and those anticipated for the connector.

4.2 Development Efforts

During this reporting period it was determined that two fiber alignment concepts, adjustable three sphere (ATS) and jeweled ferrule (JF), would be given primary consideration for this program. Prior experience with these alignment approaches, under company as well as ECOM I efforts, provided a basis for this decision. However, since

prior investigations on these approaches involved Corning fibers, an examination of the ITT fiber/cable parameters was necessary. Thus, the effort covers three general areas:

a. Fiber investigations (characterize for connector requirements)

b. Design, fabricate, and test fiber/connector assemblies

c. Alignment evaluation on cable characteristics

4.2.1 Fiber Comparison

Initial fiber investigations addressed the obvious differences in the ITT EOPD fiber/cable designs relative to the previously used Corning fibers. These differences required changes in ATS as well as JF features.

a. ITT fiber core diameter, 55 μm;
Corning fiber core diameter, 85 μm

b. ITT fiber jacket diameter, 1.02 mm;
Corning fiber jacket diameter, ∿0.130 mm

c. ITT fiber is helically wrapped in cable;
Corning is run in a loose tube

Also, various features relating to design variations in the seven ITT EOPD cables were evaluated as they interacted with the connector termination process.

Samples of EDM designs 1, 2, and 3 were subjected to a series of cleaving tests. Differences in the end face cleave quality, using previously developed techniques, were observed in fibers from designs 1 to 3. ITT EOPD tried to identify possible variations in the fiber process as a cause for these differences; the results were inconclusive.

Additional fiber evaluations were performed in conjunction with termination experiments and preliminary connector loss measurements.

In terminating fibers in the ATS ferrules, it is required that the three spheres close radially inward upon the fiber. To accomplish this, an assembly torque wrench specifically designed for this is used. This tool incorporates an adjustable slip clutch set to preclude fiber crushing. It was observed that when used with samples of the ITT fiber, an apparent tendency toward fiber breakage occurred. Due to the random nature of the breakage, a study of fiber strength under various crush loads was conducted.

To perform this study, a fixture simulating the three-sphere ferrule was devised. Two spheres are held fixed in place, tangent to each other, while a third sphere with a gage mounted could be moved radially in the fixture. The force necessary to crush a fiber was measured while observing the point of contact of the fiber and spheres with a microscope. Results obtained using this apparatus indicated a range of crush forces from 0.18 to 3.6 kg with an average of 1.3 kg for ITT fibers. When similar tests on Corning fiber were performed, a narrower range of crush forces was obtained with an average of approximately 2.3 kg.

During the course of these tests, 15 cm lengths of fiber from ITT EOPD design 1 were tested at 0.5 cm increments. Samples from all seven fibers in the cable were tested and appeared to exhibit a periodicity in the crush force to break. The periodicity may correlate with the period of the helical wrap within the cable which is approximately 5.1 cm. Since the Corning fiber was not cabled, no examination for this effect was made.

In seeking correlation for the crush data, an attempt to relate it to fiber diameter variation was made. Although the fiber diameter was found to fluctuate from 124 to 133 μm along several samples, no correlation was observed.

As a result of these studies, it was determined that a more precise setting of the slip clutch assembly would allow ITT fiber to be terminated for testing the connector concept.

4.2.2 Six Channel Connectors (Plugs and Receptacles)
All hardware components for the critical design review (CDR) were manufactured. Due to the differences between ITT and Corning cable construction and size, the connector strength member clamp strain relief mechanisms and sealing components were modified. Sufficient ATS and JF connector components were manufactured to yield two mated connector assemblies. The jeweled ferrules and adjustable three-sphere ferrules were designed to be interchangeable within the connector body. This would allow alignment concept evaluation without changing the costly connector components.

A total of 24 ATS ferrules was received from the vendor for evaluation. A dimensional inspection of all components was performed, and it was found that the gap control spring was not properly closed and ground. This would affect the uniform pressure needed to seal the ferrules from the environment. Several ferrules were terminated (using cable design 3) in the connector housing and the coupling was measured. A random instability problem was observed in the ferrule positioning. The ferrules were slightly modified and retested. The instability problem was eliminated. A few of the random matings exhibited coupling losses over 1 dB and it is believed that these matings are due to factors such as dust, keying, and core diameter variations. Table 4-1 shows the coupling losses of 263 matings.

Two hundred and twenty-five matings had coupling losses lower than 1 dB. Thirty-five matings had coupling losses lower than 2 dB, and only three exceeded 2 dB.

Table 4-1. Adjustable Three-Sphere Coupling Losses.

Coupling Loss (dB)	Frequency
.10	8
.20	16
.30	36
.41	28
.51	28
.61	32
.71	31
.81	26
.92	20
1.02	2
1.12	10
1.22	4
1.33	10
1.43	5
1.63	1
1.84	1
1.94	2
2.35	1
2.55	1
3.58	1
TOTAL EVALUATED	263

Other factors that must be considered when evaluating the data include:

a. LED drift was identified as causing up to ±0.15 dB variation in connector coupling loss.

b. Fiber outside diameter (od) variation was found to be as great as 9 μm. This could account for as much as 0.55 dB alignment loss.

In subsequent testing, four mated pairs of six-channel connectors have been terminated. Two contained jewel ferrules and two utilized ATS ferrules. During the termination process, difficulty was experienced with the fiber/cable being used (cable design 4) because the Hytrel® fiber jacket was more rigid than previously experienced. This caused a high rate of accidental breakage when handling the stripped fiber.

When a pair of connectors is mated, the abutting ferrules must move toward the back of the connectors to absorb component dimensional tolerances. Since the cable strength member was secured at the rear of the connector, the fiber was allowed to flex (bend) within a chamber between the

ferrule and the Kevlar® strength member clamp. The length of this flex chamber had been developed and tested previously with initial fiber samples. When the connectors with EDM cables were mated and the fibers flexed, coupling losses were not as low as in initial tests. This was seen in both JF and ATS connectors, indicating that the fibers were more sensitive to bending losses.

4.2.3 Cable Strain Relief Assembly

Tensile tests were conducted to determine the cable clamping effectiveness. Data indicated that the fibers within the connector move 1.90 mm axially due to the cable strain under 180 kg load. A service length that will allow for this movement will be included during ferrule termination.

4.2.4 Connector Loss Measurements (Initial Design)

Coupling loss measurements were performed on two pairs of ATS as well as two pairs of JF alignment design connectors using cable design 3. In each case, the

mated pairs were initially assembled as the design required including securing the Kevlar® strength members. The fiber ends were measured, stripped, and cleaved for the ATS design while those intended for JF use were polished in the ferrules. Installation into the connector bodies was made allowing for the fiber flex discussed earlier. Glass fiber or buffer jacket retention in the ferrules was accomplished using epoxy. Coupling losses obtained on ATS pair 1 and both JF pairs are presented in Table 4-2.

Considering the relatively poor performance noted during the connector coupling loss test when compared to earlier ferrule-only tests (Table 4-1), attempts to identify major causes of the high loss were pursued on all mated pairs.

Due to the possible contribution of fiber bend losses and fiber stiffness which hinders proper ferrule mating, it was decided to attempt an assessment of their contribution to the ATS connector loss. In assembling the

Table 4-2. Coupling Loss (dB).

ATS Connector 1		JF Connector 1		JF Connector 2	
Channel No	Loss	Channel No	Loss	Channel No	Loss
1	3.5	1	3.17	1	3.0
2	-	2	3.59	2	2.23
3	-	3	-	3	16.02
4	3.0	4	10.08	4	19.85
5	3.4	5	2.51	5	4.03
6	0.8	6	1.41	6	-

NOTE: Absence of data results from fiber breakage during assembly procedures.

connector/ferrule to the cable, an estimated suitable amount of buffered fiber was placed in the flex chamber area of the connector. If the amount of fiber included there resulted in an excess bend loss under normal conditions, the connector loss would decrease if the bend radius were increased. To verify this, the cable extending from the connector housing was subjected to a pulling force sufficient to partially straighten the fibers (increasing the bend radius). This pulling force was applied by hand while the connector loss was measured. Results of this effort appear in Table 4-3.

Based on the noted improvement over the first data, the connector was disassembled and reassembled after redressing the fibers to remove as much of the bend as possible. Upon reconnecting, the loss data in Table 4-3 was obtained. A continuously improving loss figure for those fibers operating was noted. Channel 6 exhibited somewhat erratic behavior and upon close examination it was observed to have broken during the above testing. The

Table 4-3. Coupling Loss (dB) ATS Connector 1 (Modified Test).

Channel No	Pulling Test	Redressed Test
1	2.0	1.34
2	-	-
3	-	-
4	2.7	1.5
5	2.0	0.76
6	4.5	2.25

breakage of channel 6, in conjunction with the superior initial loss values, indicates that it was probably shorter than the others and most likely snapped during the pulling test.

Considering the improved performance observed in ATS connector 1, the second ATS connector (2) was mated without securing the Kevlar® cable strength members and without the shell and coupling nut. Since the ferrule design requires a small amount of backward motion upon mating, the secured fiber bend will increase (radius decreases) and possibly cause a higher than anticipated loss. In omitting the securing components, the fiber and cable are free to move backward as necessary, due to the mating action, without changing the fiber bend. Coupling loss measurements obtained with this configuration appear in Table 4-4. Although the cable mass is unsecured and is subject to irregular movement, the measured losses are consistent with those reported in Table 4-3.

Having demonstrated the alignment concept satisfactorily, attempts to install the ferrule assembly within the shell

Table 4-4. Coupling Loss (dB) ATS Connector 2 (Strength Member Not Secured).

Channel No	Without Shell/ Coupling Nut	With Shell 1	With Shell 2
1	1.6	1.4	1.27
2	0.97	-	-
3	1.8	3.0	2.7
4	0.76	2.1	1.4
5	-	-	-
6	1.2	1.6	-

hardware were made. Two attempts to accomplish this were made with loss measurements performed after each attempt. Data corresponding to these efforts is presented in Table 4-4. It should be noted that the Kevlar® clamping assembly was not installed at this time, and the cable is not secured. Due to the movement of the cable, the fiber's stiffness, and the small amount of fiber protection afforded by the connector shell in this configuration, other fibers were broken in handling.

If, as the ATS connector tests indicate, fiber bend or flex is contributing to the loss mechanism in the connector tests, similar changes in performance should be observable in the JF design by changing the fiber securement in the shell. A quick assessment of this was provided by disassembly of JF connector 1 and by performing an individual hand mating of each ferrule pair outside of the connector. Results of this examination appear in Table 4-5. A comparison of these individual channel losses, with the corresponding channels and connector of Table 4-2, demonstrates improved performance of the alignment scheme by removing the fiber bend radius.

Table 4-5. Coupling Loss (dB) JF Connector 1 (Hand Coupled).

Channel No	Loss
1	1.8
2	2.1
3	-
4	7.6
5	1.6
6	0.8

Using fibers with high flex modulus interferes with the proper mating and aligning of the fibers within the two types of ferrules, thereby resulting in higher connector losses. This, coupled with the fiber flex loss, contributes to the excess losses reported above.

The test results for these initial connector designs indicate that either or both could be made to meet the objectives of this effort. It is important, however, to select the best approach to accomplish the needed improvements. Two methods of decreasing the connector losses are as follows:

a. Redesign the connector flex chamber and ferrule keying to accommodate a fiber having reproducible bend loss and stiffness

b. Modify the fiber buffer stiffness to reduce the effective losses in the connector

Also, in considering the best approach, the fiber/cable parameters must be evaluated in terms of reproducibility as well as ability to meet the cable assembly requirements of the program.

5.0 WORK PLANNED FOR NEXT PERIOD

The following items will be completed or addressed during the next 6-month period:

a. Program review - Discuss cable/connector interface items and cable low temperature fiber performance

b. Connector development - Modify and evaluate existing connectors to reduce cable assembly losses

c. Cable design - Select cable design based on the data generated; one of the cable designs will be selected for further fiber optimization

d. Initiate effort to address low temperature fiber performance

e. Obtain additional fibers to construct cables for final cable/connector assemblies

f. Complete optical measurements on fibers for final cable/connector assemblies

g. Initiate cable fabrication for final assemblies

APPENDIX A

OPTICAL FIBER ATTENUATION MEASUREMENT SPECIFICATION INTERIM PROCEDURE

APPLICATION		REVISIONS				
NEXT ASSY	USED ON	LTR	DESCRIPTION		DATE	APPROVED
		A	SCO # 7359	JK	5/29/79	

OPTICAL FIBER ATTENUATION
MEASUREMENT SPECIFICATION

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ROANOKE, VIRGINIA 24019

OPTICAL FIBER ATTENUATION
MEASUREMENT SPECIFICATION

SIZE	CODE IDENT NO.	DRAWING NO.
A	13567	RTTJ 211599

SCALE | REV. A | SHEET 1

1.0 SCOPE:

This specification describes the equipment and procedures required for the measurement of attenuation in optical fibers. The attenuation of an optical fiber has major impact on optical fiber system design and is essential for optical fiber characterization.

2.0 REFERENCE DOCUMENTS:

2.1 DOD-STD-1678, "Fiber Optics Test Methods and Instrumentation," 30 November, 1977.

3.0 EQUIPMENT: (See Figure 1)

Light Source	(A)	American Optical Model AO653
Modified Slide Projector	(B)	Kodak Model 650H
Filters	(C)	.47 to 1.09 um, Corion
Light Chopper	(D)	Princeton Applied Research Model 125A
Injection Lens	(E)	Variable Aperture Type Ampex Model C15-7801
PCS Fiber	(F)	ITT
Collimating Lens	(G)	
Variable F-stop	(H)	Part #Ampex Model C15-7801
Test Fiber		
Output Lens		
Detector	(J)	Egg #SGD-444
Lock-in Amplifier	(L)	Princeton Applied Research Model 124 with Model 185 Preamp

4.0 MATERIAL:

4.1 Masking Tape (Stock #016007)

4.2 Razor Blades (Stock #026008)

4.3 Diamond Scribe RTVA 211,586

4.4 T.7. Corona Dope RTVA 211585

4.5 Magnifying Glass x5 minimum (Optional)

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SIZE	CODE IDENT NO.	DRAWING NO.	
A	13567	RTVJ 211599	
SCALE	REVISION A	SHEET 2 of 6	

5.0 PROCEDURE:

5.1 Set-up

5.1.1 Check that lock-in amplifier (L) controls are set as shown in Figure 2. With input applied, adjust phase for zero output when phase changed by 90°.

5.1.2 Check that power supply (K) is set at 100V with the detector (K) reverse biased (cathode positive potential).

5.1.3 Turn all equipment on.

5.2 Graded index and step index CVD fibers.

5.2.1 (Long length) Prepare ends on each end of test fiber per specification RT-VJ-211,570 . Leave 5.0 to 7.6 cm (2.0 to 3.0") of bare fiber exposed at each end. A good reflection of room light from the fiber end is adequate to determine suitable end quality.

5.2.2 Coat the entire surface of the exposed fiber with T.V. corona dope to within 0.5 cm (0.2 in.) of each end. This strips light propagating in the substrate glass. Caution is required to avoid contacting the fiber end with the T.V. corona dope. Allow to dry.

5.2.3 Position end of pull (EOP) fiber end on 5-axis positioner P_1 in slot provided in fixture.

5.2.4 Position start of pull (SOP) fiber end in detector fixture, P_2 using alignment rods to place end in proper position. Move fixture into detector until stop reached.

5.2.5 Set the slide projector controls for white light injection. Set the valuable F-stop lens H to F2 (NA = .243). Adjust positioner P_1 for maximum throughput as indicated by the output of the lock-in amplifier K. Adjust lock-in scales as required. Adjust time constant as required to obtain steady state reading.

5.2.6 Adjust slide projector to obtain filter at desired wavelength. Adjust F-stop on lens (H) for desired NA. Record steady state value and scale from lock-in amplifier (K).

5.2.7 Repeat for additional NA's at the same wavelength.

5.2.8 Repeat for each additional wavelength required.

5.2.9 (Short Length) Remove SOP from detector. Cut fiber approximately one meter (39.4 inches) from EOP. Prepare end at point cut on one meter section per 5.2.1 and 5.2.3.
NOTE: Extreme care should be exercised to avoid disturbing the EOP end during this step.

5.2.10 Position the new end in the detector per 5.2.4. Repeat steps 5.2.5

SIZE	CODE IDENT NO.	DRAWING NO.
A	13567	RT-VJ 211,599
SCALE	REVISION A	SHEET 3 of 5

5.2.10 (Cont.) through 5.2.3 as during the long length measurement per requirements.

5.3 Single Mode Fibers

5.3.1 (Long Length) Prepare ends on each end of fiber per specification RT-VJ-211,570 . Leave 10.2 to 12.7 cm (4.0 to 5.0 in.) of bare fiber at each end. The end should be inspected under 10X magnification to determine end suitability. Minor flaws are permissible on fiber edges, but a smooth, flat central region is essential.

5.3.2 Perform measurement per 5.2.2 through 5.2.10 except the short length shall be 5 m long and the new end on the short length is prepared per 5.3.1.

5.4 Plastic Clad Silica (PCS) Fiber

5.4.1 Prepare both fiber ends per specification RT-VJ-211,570 . Only ~0.5 cm (.127 in.) of bare fiber is required. No T.7. corona dope is required as light does not propagate in the plastic cladding.

5.4.2 Perform attenuation measurement per 5.2.3 through 5.2.10.

5.5 Data Reduction

Substitute lock-in amplifier readings into equation below:

$$\alpha \text{ (dB/km)} = \frac{10}{L} \log 10 \frac{V_o}{V_1} (\lambda_o, NA_o) \qquad (1)$$

Where, L = fiber length in km

λ_o = chosen filter wavelength

V_1 = short length voltage reading at λ_o and NA_o, multiplies by scale.

V_o = long length voltage reading also at λ_o and NA_o, multiplied by scale.

NA_o = specified TV lens NA

(V_1 and V_o are reduced by synchronous spurious signal, level for very low signal levels)

6.0 <u>ACCEPT/REJECT</u>:

6.1 Not needed

7.0 <u>DELIVERY/ STORAGE</u>:

7.1 Not needed

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A	13567	RT-VJ 211,599
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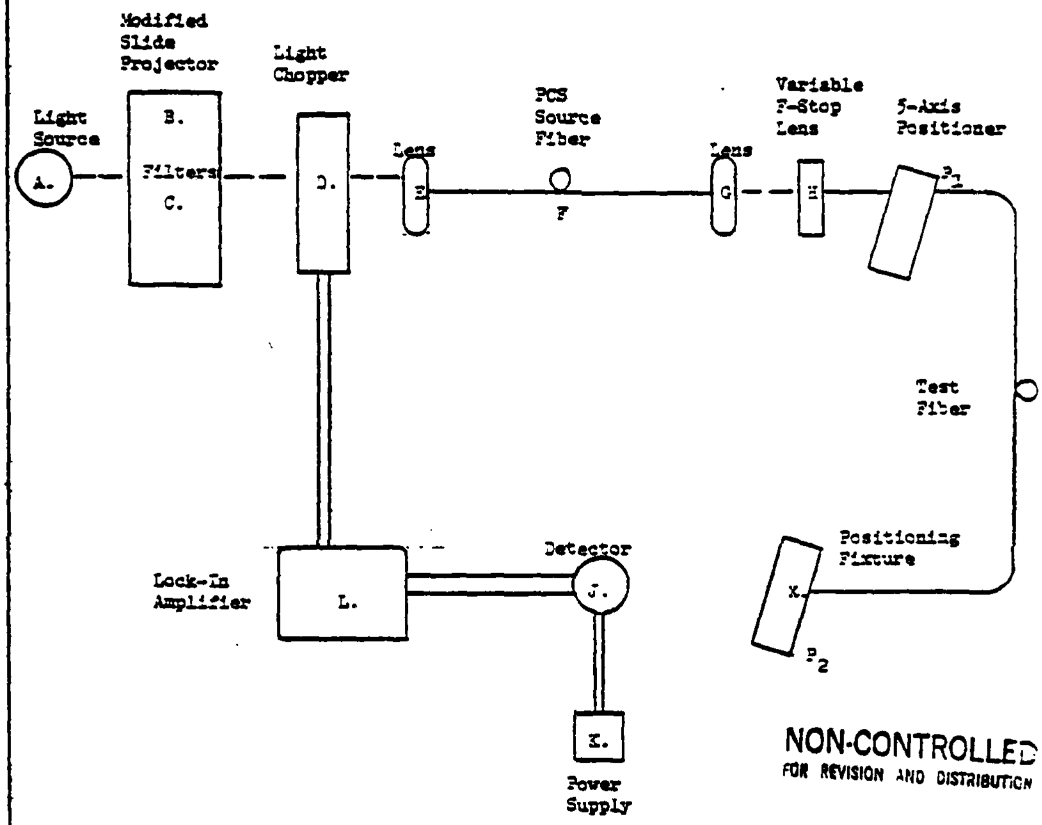

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ATTENUATION MEASUREMENT APPARATUS

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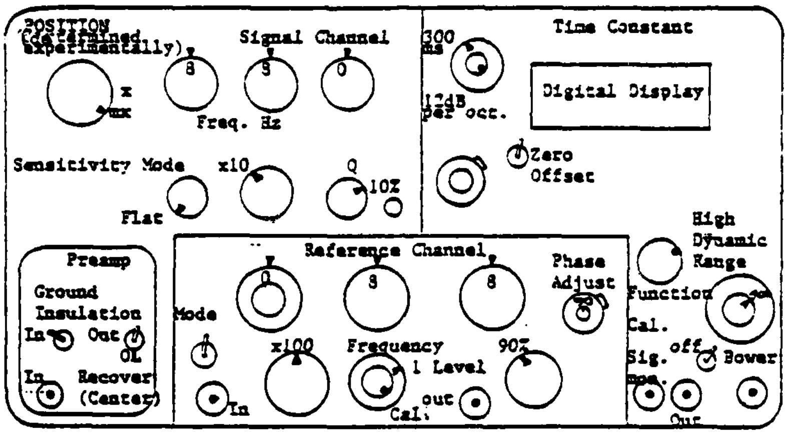

LOCK-IN AMPLIFIER DIAL SETTINGS

FIG. 2

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A	13567	RT-VJ-211,599
SCALE	REVISION	SHEET 5 of

APPENDIX B

FIBER PULSE DISPERSION

MEASURED AT 0.9 μm

INTERIM PROCEDURE

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APPLICATION		REVISIONS				
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FIBER PULSE DISPERSION

MEASUREMENT AT 0.9 um

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FIBER PULSE DISPERSION

MEASUREMENT AT 0.9 um

SIZE	CODE IDENT NO.	DRAWING NO.
A	13567	RTVJ 211600

SCALE	REV. A	SHEET 1 of 7

1.0 SCOPE:

The purpose of this measurement is to determine the pulse broadening of an optical fiber at an operating wavelength of 0.9 um. The pulse broadening, or dispersion, determines the information capacity of the fiber. This specification applies to 0.9 um dispersion measurements of both graded index and step index CVD fibers.

2.0 REFERENCE DOCUMENTS:

2.1 DOD-STD-1678 "Fiber Optics Test Methods and Instrumentation."

3.0 EQUIPMENT:

3.1 Electronic Equipment

Quantity	Description	Nomenclature For Diagram
2	Fluke 415B High Voltage Power	PS1, PS2
1	Heath SP-2730 High Current Power Supply	PS3
1	Lambda LL-903-OV Power Supply	PS4
1	RCA-SG2001 GaAs Laser and Driver	L
1	Borg Warner CP1.4-17-10L Thermoelectric Cooler	TEC
1	Tektronix 7603 Oscilloscope Mainframe	SO
2	Tektronix 7S11 Sampling Units	SO
2	Tektronix S-4 or S-2 Sampling Head	SO
1	Tektronix 7T11 Time Base	
1	ITT Pocket Scope Image Intensifier	I.I.
1	Hewlett-Packard 8447D .1 to 1300 MHz Amplifier	A
1	Dispersion Pulse Controller or Berkeley Nucleonics Corporation 7075 Digital Delay Generator	DDG
1	RCA C30902E Avalanche Photodetector	APD
1	Hewlett-Packard 5082-4203 PIN Diode	PIN
	Hewlett-Packard 7035B X-Y Recorder	X-Y

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A	13567	RTVC 211600
SCALE	REVISION REV. A	SHEET 2 / 7

3.2 Optical Equipment

Quantity	Description	Nomenclature for Diagram
1	Set of lenses and microscope objectives	
1	3-Axis Micropositioner	
1	5-Axis Micropositioner	
1	Assorted Optical Rails and Stands	

3.3 Miscellaneous

1	Diamond Scribe RTJA 211586	
1	Vernier Caliper	

4.0 MATERIAL:

Description	Stock Room Number or Manufacturer
Razor Blades	026-008
Graph Paper	005-009
Masking Tape, 1.0"	016-008
TV Corona Dope	RT-VA-211585

5.0 PROCEDURE:

5.1 Measurement Procedure

5.1.1 Place a new piece of graph paper in the X-Y recorder and turn the recorder switch on. Also, turn the chart switch to hold. Record the preform number and fiber identification number of the test fiber.

5.1.2 Make a short end, leaving approximately 6.3 mm (.25") of bare fiber exposed, on the end of pull, marked EOP. Use the procedure of Specification RT-VJ-211,5TC . Visual confirmation of room light reflection from the entire fiber end face is adequate to assure a suitable end. Clean the fiber end face with masking tape. Place the fiber in the 5-axis positioner so that the end is flush with the end of the groove.

5.1.3 Set control switch on the laser power supply, PS1 to "standby" position. Turn on the digital delay generator, DDG.

5.1.4 Set the sampling oscilloscope on left channel and to 10 ns per horizontal division.

5.1.5 Set the X100 knob on the digital delay generator at 1. Set the "REV" switch to the counterclockwise (reversed delay) position. This

SIZE	CODE IDENT NO.	DRAWING NO.
A	13567	RTVJ 211600
SCALE	REVISION A	SHEET 3 of 7

5.1.5 (Cont.) retards the triggering pulse, allowing the operator to view the input pulse on the scope.

5.1.6 Set the laser power supply voltage, PS1, to 5 V above the threshold voltage specified for the laser in use, and turn control switch to "on" position.

5.1.7 Adjust the time position on the sampling oscilloscope until the trace of the laser pulse is at the far left hand side of the screen.

5.1.8 Make an end, leaving approximately 7.6 cm (3.0") of bare fiber exposed, on the start of pull of the fiber, marked SOP. Use the procedure of Specification RT-VJ-211,570. Visual confirmation of room light reflection from the entire fiber end face is adequate to assure a suitable end.

5.1.9 Apply TV Corona Dope over approximately 5.1 cm (2.0") of the bare fiber, being careful not to contaminate the end. This will remove light propagating in the fiber cladding.

5.1.10 Clean dust particles from the end face by touching the end face to the sticky surface of a piece of masking tape. Place the fiber end in the 3-axis positioner so that the end face is flush with the end of the fixture groove.

5.1.11 Turn off room lights and view the end of the fiber with the image intensifier.

5.1.12 Maximize the intensity of the image by adjusting the 5-axis positioner.

5.1.13 Turn on the APD power supply, PS2. Set PS2 control switch to "standby" position. Place this 3-axis positioner in front of the APD detector lens train and against the stops. Check that PS2 is set to 200 V or the voltage specified for the device in use. Turn PS2 control switch to "on" position.

5.1.14 From the estimated length as supplied with the fiber, estimate the delay from the table on the wall of the laboratory. Set the controls on the DDG to the approximate delay. Adjust until the pulse is visible on the scope.

5.1.15 Adjust the 3-axis positioner for maximum intensity and record the delay (in nanoseconds) from the digital delay generator. Add 100 ns to the delay time. This is due to the internal preset delay of the dispersion pulse controller.

5.1.16 Adjust the 3-axis micropositioner to maximize the total area of the signal, as viewed on the sampling oscilloscope.

5.1.17 Spread the curve for best viewing by adjusting the timebase to the appropriate scale. Adjust the 5-axis positioner to maximize the area of the curve.

5.1.18 Adjust the laser power supply so that the laser is 1 volt above

SIZE	CODE IDENT NO.	DRAWING NO.
A	13567	RTVJ 211600

SCALE	REVISION A	SHEET

5.1.19 Set the sampling oscilloscope scan on "manual."

5.1.20 Turn the switch of the X-Y recorder to the "SERVO" position. Adjust the trace controls on the sampling osciolloscope to fit the X-Y recorder, then turn the scan to the far left.

5.1.21 Set the pen down and turn the "PEN" switch to the "DOWN" position.

5.1.22 Adjust the scan control on the sampling oscilloscope to make one trace.

5.1.23 Lift the pen and return it to the left side with the scan control.

5.1.24 Reduce the laser voltage one volt and make a second scan.

5.1.25 Record the sweep range setting in ns/in. (1 oscilloscope div.=1 in on X-Y recorder outputs)

5.1.26 Record the right channel voltage in mV/in.

5.1.27 Initial the sheet in upper right hand corner. Set both power supplies, PS1 and PS2, to standby position.

5.1.28 Turn off both power supplies, the digital delay generator and the sampling oscilloscope, if no further work is scheduled.

5.2 Data Reduction Procedure

5.2.1 Referencing the graph obtained in the dispersion measurement, call the upper trace the laser trace and the lower trace the LED trace.

5.2.2 (Step Index Fibers Only) Draw a straight line between the end points of the LED trace, call this line the base line.

5.2.3 (Graded Index Fibers Only) With the Vernier calipers, find the maximum vertical separation ($d_v$max) between the laser trace and the LED trace.

5.2.4 (Step Index Fibers Only) With the Vernier calipers, find the maximum vertical separation ($d_v$max) between the laser trace and the baseline.

5.2.5 Calculate the vertical separation corresponding to the specified magnitude (% peak) multiplying the peak verticle separation, $d_v$max, by $\frac{\%\ \text{peak}}{100}$.

5.2.6 Set the calipers at the specified separation between the two curves.

5.2.7 Find the two points that have the same vertical separation between the curves as the new caliper setting and mark them.

5.2.8 Measure the horizontal distance between these two points. Multiply this number by the sweep range setting in nanoseconds. Record this number on the sheet. Call this number the output pulse width, W_o.

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SCALE	REVISION	SHEET
	A	6 / 7

5.2.9 Divide the delay, in microseconds, by 4.94 ns/km and record this number as the length in kilometers.

5.2.10 Find the dispersion by using the formula

$$D_{(xx\%)} = \frac{1}{L} \times \sqrt{W_o^2 - W_1^2}$$

where L is the length of the fiber previously calculated in kilometers, W_o is the width in nanoseconds of the output pulse, xx is the magnitude percentage where the dispersion is measured, and W_1 is the input pulse width (provided). Record the dispersion in nanoseconds per kilometer on the sheet and on the attenuation sheet which accompanies the fiber.

6.0 ACCEPT/REJECT:

6.1 Not needed

7.0 DELIVERY/STORAGE:

7.1 Not needed

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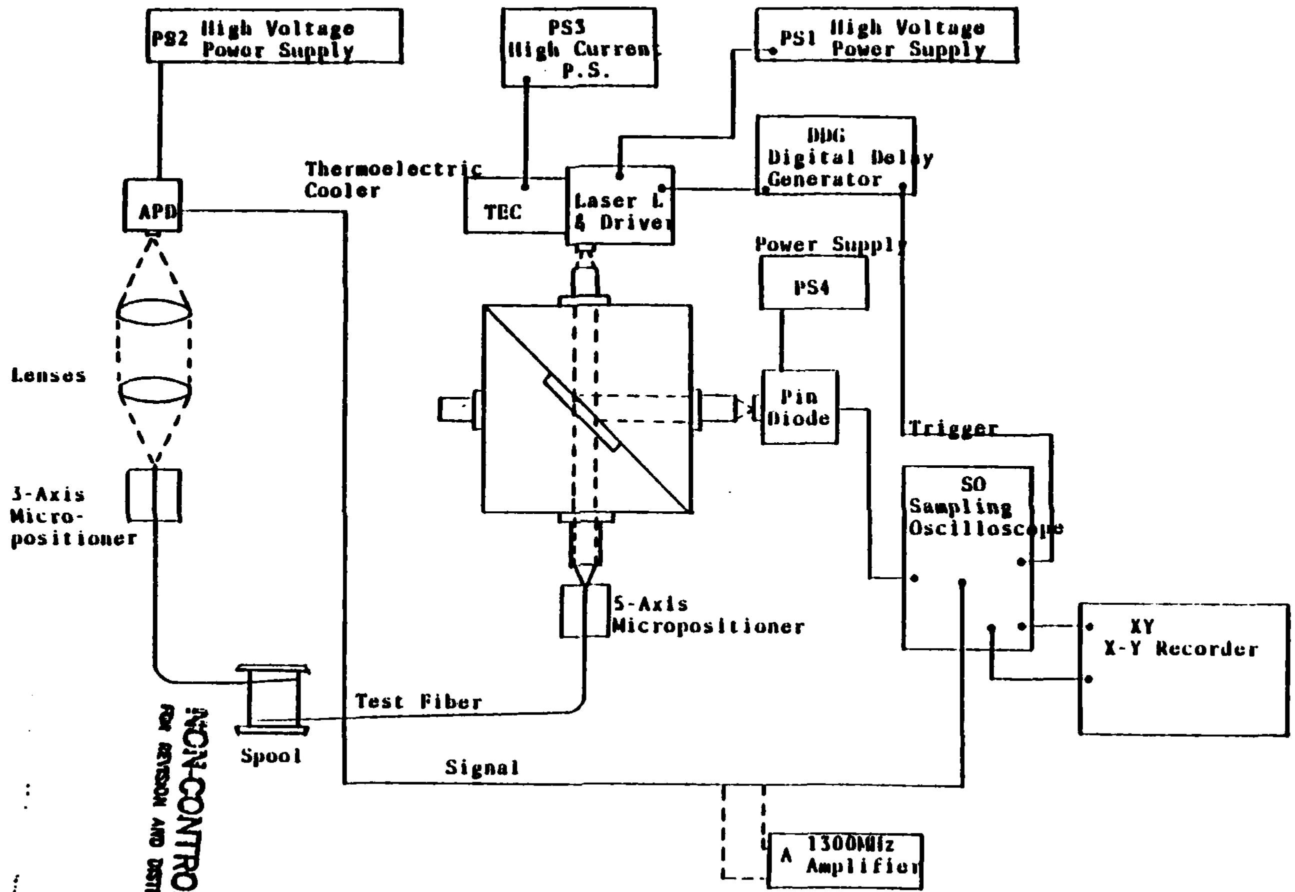

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Sheet 7 of 7 Rev. A

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